IRON ORE COMPANY OF CANADA

PROJECT 7224-N004

EVALUATION OF THE ORGANIC BINDER PERIDUR 2.30 IN THE PELLETIZING OF CAROL CONCENTRATE

By

Guy Paquet, Eng.

Final Report
June 14, 1991

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SUMMARY

This report describes the results of a study on the performance of Peridur 2.30 in the pelletizing of Carol concentrate. The pot grate testwork was conducted at the CRM pilot plant.

The organic binder was evaluated in relation to its performance during balling and its impact on pellet quality. Full and partial bentonite substitution was considered as well as the effect of additives such as limestone, dolomite and bauxite. The Peridur 2.30 was also evaluated in the making of fluxed pellets.

Significant progress has been made during the course of this project. A much better understanding of the impact of Peridur on pellet quality was gained.

Recommendations are made for the next phase of the bentonite substitution program. They include a commercial trial to identify other possible problems during balling and some additional pot grate testwork to optimize the quality of fired pellets.

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1. INTRODUCTION

Previous research work at CRM showed the high potential of the organic binder "Peridur" for the substitution of bentonite in the pelletizing process.

However, problems such as higher pellet swelling and poor tumble index were associated with the use of the organic binder.

The research efforts for improving the Peridur were intensified and a new product, more adapted to Carol concentrate, was developed.

The objective of this project was to evaluate the performance of this new binder in the balling process and to measure its impact on acid and fluxed pellet quality.

2. CONCLUSIONS

Laboratory and pot grate testwork with the organic binder, Peridur 2.30, led to the following conclusions:

1. On a complete bentonite substitution basis, the optimum addition rate of Peridur 2.30 appears to be around 0.07 %

2. A small addition of bentonite (0.1 to 0.2 %) helps in controlling the balling process by decreasing the sensitivity to filter cake moisture variations. The small addition of bentonite is specially helpfull at high moisture levels.

3. Because of the small quantity of Peridur added, a good mixing of the binder with the ore is difficult to achieve. Pre-mixing of Peridur with other additives such as limestone, dolomite, etc., improves its performance.

4. The binder named "Peridur DS" showed a performance similar to Peridur 2.30 with the exception of lower dry ball strength. A better control of green ball moisture, likely due to a higher absorption capacity, was noted.

5. The effect of Peridur on acid pellet quality can be summarized as follows :

   - The tumble index (% + 6.3 mm) is 0.5 to 1.0 % lower than for bentonite pellets.

   - Fired pellet compressive strength is comparable.

- Peridur acid pellets seem to require a slightly higher firing T °.

- The reducibility of Peridur pellets is about 0.20 % O_2/min higher than for bentonite based pellets. This is one of the major benefits of Peridur.

- The swelling of Peridur acid pellets (~ 30 %) is considerably higher and exceeds the acceptable level of 20 %.

- The Low Temperature Desintegration (LTD) properties are not much affected when using Peridur in the making of acid pellets.

- The recycling of Peridur pellets as hearth layer revealed a 10 % deterioration of their strength. This is comparable to bentonite acid pellets.

- Softening T ° of both types of pellets were comparable.

6. The addition of a small quantity of dolomite to Peridur pellets improved the tumble index and compressive strength. A small decrease of pellet swelling was also noted but not enough to reach an acceptable level. Dolomite had an adverse effect on LTD and should be considered with care.

7. The addition of a small quantity of limestone improved the overall quality of Peridur acid pellets. The swelling was slightly lower and a clear improvement of the pellet strength was observed (tumble, compressions and LTD).

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8. A small addition of bauxite considerably decreased the swelling of Peridur pellets. However, the pellet reducibility also drastically decreased to reach a level comparable to bentonite pellets. These effects are believed to be due to the presence of alumina which has a favorable role in the kinetic of fayalite formation. The fayalite is a low melting phase which inhibates the reduction process.

9. The overall quality of Peridur fluxed pellets was superior to bentonite fluxed pellets with the exception of a small decrease in the tumble index (less than 0.5 %). Compression, swelling and softening T ° results were equivalent. Clear improvements were noted in R_{40} and LTD (both static and Jumbo dynamic). The compressive strength of hearth layer Peridur pellets decreased by about 15 % which is comparable to bentonite fluxed pellets. However, recycled Peridur pellets showed much better LTD results than bentonite based pellets.

Significant progress has been made during the course of this project. It can be expected that the remaining problems associated with the use of Peridur will be resolved in a near future.

3. RECOMMENDATIONS

Additional pot grate testwork is required to investigate the following :

- If partial substitution is to be considered, determine the optimum combination Peridur - Bentonite in relation to balling control as well as green ball and fired pellet quality.

- Develop a better understanding of the role of additives such as dolomite, limestone and bauxite.

- Consider the use of more than one additive to optimize the quality of Peridur acid pellets. For example, it can be expected that the combined effect of limestone and bauxite may lead to an optimum pellet quality. Other combinations of additives (including bentonite and dolomite) should also be considered.

- Elaborate a program to determine the optimum firing conditions (bed depth, firing T °, % coke, etc.) for Peridur pellets.

- Evaluate the effect of the ore particle size on the performance of Peridur during balling and on pellet quality. It is suspected that the actual ore grinding level may not be ideal for Peridur.

- Clarify the role of alumina and its impact on pellet quality.

At this stage, a commercial trial on one pelletizing line at Carol Lake is suitable to indentify other possible problems associated with the use of the organic binder. This trial should be performed before or during the above recommended pot grate testwork so that the findings may be considered in pilot scale work. The procedure for mixing Peridur with the filter cake should also be well established.

The opening of new markets and the evolution of the steelmaking technology have created more pressure on pellet quality. In future testwork, more attention should be given to Jumbo dynamic LTD, Softening and Fusion T • as well as mineralogy and pellet structure.

4. EXPERIMENTAL PROCEDURES

The balling and firing tests were done according to standard procedures. These procedures are well known and were described in details in previous projects. The diameters (I.D.) of the balling disk and pot grate were respectively 100 and 38 cm.

The mixing of the ore and additives was accomplished in a Sturtevant mixer. In some cases, a special mixing procedure was used to ensure a better distribution of Peridur in the mix. The binder was pre-mixed with either dry ore or another additive to increase the volume of material to be mixed with the filter cake and, thus, improve the homogeneity. All the mixes were adjusted to 9 % H_2O prior to balling.

The chemical analysis of all the additives are shown in table 1.

Bentonite, limestone, dolomite and coke breeze "American" were supplied by IOCC. The 3 last were dried and ground at our pilot plant to approximately 75 % -200 mesh. Grinding was performed in a ball mill.

The bauxite sample was supplied by Dofasco and is excepted to be representative of what they are adding to the blast furnaces. The raw bauxite (2 to 8 cm) was crushed and ground to 77 % -200 mesh at our pilot plant. According to the grinding time it can be assumed that the hardness of bauxite is approaching that of coke breeze.

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TABLE 1

CHEMICAL ANALYSIS OF THE ADDITIVES

ADDITIVE	Fe2O3	SiO2	CaO	MgO	Al2O3	TiO2	MnO	P2O5	Na2O	K2O	LOI
BENTONITE	4.56	53.80	3.10	2.99	17.20	0.74	0.09	0.21	2.51	1.24	13.80
DOLOMITE	0.30	3.62	29.20	20.80	0.15	<0.01	0.01	0.03	0.13	0.03	45.20
LIMESTONE	0.31	0.84	54.30	0.86	0.20	<0.01	0.01	<0.01	<0.01	0.06	43.40
BAUXITE	23.00	5.71	0.56	0.21	55.80	2.54	0.10	0.08	0.23	0.47	10.60

COKE BREEZE AMERICAN

CALOROFIC VALUE : 29.060 kJ/kg (12.495 BTU/lb)

ASH : 14.4 %

VOLATILES : 3.75 %

The filter cake was supplied by IOCC in 2 different batches. The first batch was used for tests # 1 to 12 and the second batch for tests # 13 to 17.

The chemical analysis of the filter cakes and fired pellets are summarized in table 2.

The detailed firing conditions are described in appendix 1. The temperature and pressure recordings are shown in appendix 2. The original recordings were sent to IOCC.

The green ball and fired pellet properties were determined according to standard procedures as follows :

Determination	Procedure
Tumble	ASTM
Compressive strength	ISO
Porosity	ISO
R_{40}	ISO
Swelling	ISO
LTD static (2 % H_2)	ISO
LTD dynamic Jumbo (2 % H_2)	German
Softening T °	CRM - Dofasco - BSC

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TABLE 2

CHEMICAL ANALYSIS OF FILTER CAKES AND FIRED PELLETS

MIX #	FILTER CAKE (%)							ADDITIVES (%)					FIRED PELLETS (%)				
	Fe	FeO	C	SiO2	Al2O3	CaO	MgO	BENT.	PER.	DOLO.	LIMEST.	BAUX.	Fe	SiO2	Al2O3	CaO	MgO
1	65.1	9.2	0.93	5.0	0.14	0.11	0.23	-	0.07	-	-	-	65.7	4.8	0.22	0.11	0.23
2	65.1	8.6	0.95	5.0	0.12	0.12	0.27	-	0.07	-	-	-	65.7	4.9	0.11	0.18	0.22
3	65.1	8.4	1.00	4.9	0.14	0.09	0.24	-	0.09	-	-	-	65.3	4.8	0.18	0.12	0.25
4	65.1	8.3	0.97	4.8	0.21	0.14	0.25	0.20	0.07	-	-	-	65.2	N/A	0.20	0.26	0.38
5	64.9	8.5	0.95	4.8	0.16	0.14	0.21	-	0.07	0.75	-	-	65.0	4.8	0.19	0.39	0.38
6	64.9	7.6	0.98	4.8	0.11	0.21	0.26	-	0.07	1.50	-	-	64.1	4.9	0.14	0.55	0.51
7	65.1	7.9	0.96	4.8	0.12	0.11	0.23	0.80	-	-	-	-	65.4	5.2	0.14	0.11	0.25
8	64.9	7.2	0.97	4.9	0.11	0.11	0.20	0.40	0.07	-	-	-	65.2	5.2	0.14	0.07	0.27
9	65.1	8.8	0.93	4.8	0.16	0.04	0.30	-	0.07	-	0.75	-	64.5	4.9	0.12	0.56	0.28
10	65.1	8.5	0.96	4.8	0.15	0.06	0.25	-	0.07	-	1.50	-	64.1	4.9	0.15	0.99	0.25
11	65.3	8.1	0.94	4.7	0.11	0.10	0.28	-	0.07	-	-	-	65.7	4.7	0.16	0.19	0.27
12	65.8	8.1	0.97	4.8	0.10	0.04	0.27	-	0.07	-	-	1.00	65.8	4.6	0.73	0.16	0.27
				*						*					*		
13	66.7	12.2	0.59	4.0	0.18	0.08	0.28	0.20	0.05	-	-	-	66.0	4.3	0.22	0.10	0.25
14	66.2	10.2	0.57	4.0	0.15	0.28	0.31	-	0.07	7.50	3.00	-	63.2	4.0	0.21	3.40	1.73
15	66.2	10.2	0.59	3.9	0.14	0.23	0.34	0.80	-	7.50	3.50	-	62.3	4.4	0.27	3.36	1.68
16	66.4	11.8	0.59	3.9	0.19	0.12	0.32	-	0.07	-	-	0.50	64.7	4.0	0.32	0.21	0.32
17	66.4	12.5	0.60	3.9	0.14	0.20	0.32	-	0.05	-	1.00	-	64.1	3.9	N/A	0.54	0.37

* TESTS # 13 TO 17 WERE DONE WITH A NEW BATCH OF FILTER CAKE

5. RESULTS AND DISCUSSION

5.1 Tire balling tests

The results of all the laboratory tests are summarized in table 3.

Tests # 1 to 4 directly compare the performance of Peridur 2.30 with Bentonite. When considering balling behaviour and green ball quality (% H_2O, drops and wet strength), the optimum addition rate of Peridur seems to be between 0.05 and 0.07 %. A this dosage the dry ball strength is much lower than bentonite balls but, as discussed in the next sections, is still believed to be sufficient to withstand the indurating process in the industrial furnace. At dosage higher than 0.07 % the green balls become very soft and plastic and may cause some permeability problems in the furnace due to excessive deformation.

In tests # 5 to 8 the effect of a combined addition of bentonite and Peridur is evaluated. The results from tests # 5 and 6 show that a small addition of bentonite, with 0.07 % Peridur, give excellent green and dry ball strength. Test # 7 shows that bentonite can be pre-mixed with Peridur without creating any major problems. Test # 8 was done on a basis of 50 % replacement of bentonite by Peridur with excellent results.

The addition of a small amount of bentonite along with Peridur improves the water retention capacity. A bentonite-Peridur combination should be less sensitive to filter cake moisture variations.

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TABLE 3

BALLING TIRE TESTS

TEST #	% BENT	%PER 2.30	% DOLO	% H2O	DROPS	WET Kg	DRY Kg	COMMENTS
1	0.8	-	-	8.7	16	1.5	7.5	REF. BENTONITE TEST
2	-	0.05	-	8.8	11	1.2	1.8	
3	-	0.07	-	8.8	19	1.5	3.1	
4	-	0.09	-	9.1	24	1.6	4.8	
5*	0.1	0.07	-	8.8	17	1.7	6.9	BINDERS ADDED SEPARATELY
6	0.2	0.07	-	9.2	16	1.8	8.0	BINDERS ADDED SEPARATELY
7	0.2	0.07	-	9.4	18	1.7	7.3	BENT. MIXED WITH PER.
8	0.4	0.04	-	9.5	16	1.9	6.5	BINDERS ADDED SEPARATELY
9	-	0.07	0.5	8.8	19	1.6	4.4	PERIDUR MIXED WITH DOLO.
10	-	0.07	1.0	8.8	14	1.6	4.0	PERIDUR MIXED WITH DOLO.
11	-	0.07	-	8.8	19	1.4	4.1	PERIDUR MIXED WITH DRY ORE
12	-	0.07	-	7.9	10	1.4	4.3	LOWER H2O. LOWER DROP
13	-	0.07	-	STICKING AND POOR BALLING				TEST AT HIGH H2O
14	-	0.07(DS)	-	8.6	13	1.4	2.8	PER. DS MIXED WITH DRY ORE

* AVERAGE OF 2 TESTS

Tests # 9 to 11 were done with improved mixing conditions. In test # 9 and 10, the Peridur was mixed with a small amount of dolomite prior to be mixed with the filter cake. In test # 11 the dolomite was replaced by 1 % dry ore. This procedure increases the volume of material to be incorporated in the mix and improves the homogeneity. When comparing to test # 3, it can be seen that a gain of about 25 % is achieved on dry ball strength when using improved mixing conditions.

Test # 12 shows the very good response of Peridur at low green ball moisture level. However, test # 13 resulted in a very bad balling behaviour when the moisture was increased beyond 9 %. As already mentioned it is believed that a small addition of bentonite would take care of high moisture levels.

Finally test # 14 was done using the new Peridur "DS". No significant improvement could be observed from this only one test.

5.2 Acid pellets - Full and partial bentonite substitution

Tables 4 and 5 summarize the conditions and results for various tests done at different bentonite substitution levels. The firing conditions were adjusted to optimize pellet strength. The optimum tests are marked with a "+".

The replacement of 0.8 % bentonite by 0.07 % Peridur (test series # 7 Vs # 1) under similar mixing conditions resulted in :

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TABLE 4

PERIDUR\BENTONITE ACID PELLETS - TESTS CONDITIONS

TEST #	7A	7B ♦	1A	1B ♦	2A ♦	2B	3A ♦	3B	4A	4B ♦	8A ♦	8B	13A	13B ♦	13C ♦	11A	11B ♦
TEST DESCRIPTION	REF. TEST 0.8 % BENT		0.07 % PER		0.07 % PER		0.09 % PER		0.07 % PER + 0.2 % BENT		0.04 % PER + 0.4 % BENT		0.05 % PER + 0.2 % BENT			0.07 % NEW PERIDUR (DS)	
MIXING PROCEDURE	NORMAL		NORMAL		PER. MIXED WITH DRY ORE		PER. MIXED WITH DRY ORE		PER. MIXED WITH DRY ORE		PER. MIXED WITH DRY ORE		PER. MIXED WITH DRY ORE			PER. MIXED WITH DRY ORE	
% HEAT MAG. EQUIV. (%C X 64 +%MAG)	90		88		91		93		91		91		76			88	
FILTER CAKE																	
% -325 M	64.8		65.8		65.2		65.2		64.9		65.4		64.4			65.1	
BLAINE (cm2/g)	1715		1870		1630		1715		1755		1785		1725			1705	
% MAG (Satmagan)	28.7		28.5		29.8		28.5		28.8		29.3		38.2			27.7	
WET BED (cm)	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38
HEARTH LAYER (cm)	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
FIRING TIME (min)	41	41	41	41	41	41	41	41	41	43	41	43	41	41	41	41	43
t/day ft2 (G. Balls)	3.10	3.10	3.10	3.10	3.10	3.10	3.10	3.10	3.10	2.96	3.10	2.96	3.10	3.10	3.10	3.10	2.96
AIR FLOW (Nm3/m2min)																	
UDD	93	100	91	99	96	93	94	86	92	92	93	94	96	96	105	94	101
F-7	24	28	22	24	24	21	24	22	24	22	22	24	25	28	33	22	25
COOLING	89	102	89	98	98	91	95	88	97	92	93	98	100	100	107	93	101
FIRING T° MAX (°C)	1260	1260	1260	1260	1275	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260
INTERFACE T° (°C)	1220	1350	1190	1250	1295	1265	1300	1250	1330	1340	1305	1330	1215	1300	1355	1250	1275
MIN. AT T° > 1200 °C	0.3	4.2	0.0	1.3	2.7	1.7	2.2	0.8	3.3	3.7	2.0	3.5	0.3	2.3	5.2	0.8	1.5
GAS T° (°C) WB # 30	270	465	305	420	450	330	355	300	415	405	305	440	290	420	590	300	415

♦ = OPTIMUM FIRING

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TABLE 5

PERIDUR\BENTONITE ACID PELLETS - TESTS RESULTS

TEST #	7A	7B ♦	1A	1B ♦	2A ♦	2B	3A ♦	3B	4A	4B ♦	8A ♦	8B	13A	13B ♦	13C ♦	11A	11B ♦
TEST DESCRIPTION	REF. TEST 0.8 % BENT		0.07 % PER		0.07 % PER		0.09 % PER		0.07 % PER + 0.2 % BENT		0.04 % PER + 0.4 % BENT		0.05 % PER + 0.2 % BENT			0.07 % NEW PERIDUR (DS)	
GREEN BALLS																	
% H2O	8.7		9.1		8.9		8.9		9.0		9.5		9.3			9.3	
DROPS	11		17		19		19		16		19		16			17	
WET STRENGTH (Kg)	1.3		1.6		1.3		1.4		1.3		1.4		1.2			1.4	
DRY STRENGTH (Kg)	6.6		4.9		5.1		5.7		6.2		4.1		3.4			3.8	
FIRED PELLETS																	
ASTM TUMBLE																	
% +6.3 mm	94.2	96.3	93.9	95.4	96.1	95.5	95.9	95.0	95.7	95.6	95.5	95.3	93.6	95.5	95.9	94.7	95.4
% -0.5 mm	5.6	3.5	5.9	4.5	3.8	4.5	4.1	4.9	4.3	4.1	4.4	4.5	6.3	4.4	4.0	5.2	4.5
STRENGTH (Kg)																	
$\bar{x}$	250	272	257	270	271	274	253	272	255	251	256	264	272	291	287	286	277
σ n-1	67	55	49	41	42	65	51	39	48	45	53	41	58	55	54	45	57
TOP OF BED	243	256	277	274	270	289	251	268	248	255	257	264	280	295	297	289	282
MIDDLE	243	260	248	262	268	281	239	279	245	240	251	271	297	301	289	297	271
BOTTOM	263	301	245	273	275	252	269	271	271	257	258	259	241	277	300	273	280
HEARTH LAYER	-	-	-	-	-	-	-	-	-	-	-	-	-	-	262	-	-
POROSITY (%)	-	26.4	-	27.8	28.0	-	28.3	-	-	27.9	27.7	-	-	-	26.9	-	27.5
SATMAGAN (%)	-	2.7	-	1.1	1.1	-	1.4	-	-	0.8	1.5	-	-	-	0.4	-	0.5
ISO R40 (%O2/min)	-	0.54	-	0.75	0.74	-	0.75	-	-	0.71	0.69	-	-	-	0.72	-	0.62
ISO SWELLING																	
% VOL	-	20.6*	-	30.5	28.3*	-	31.0	-	-	28.7	26.0	-	-	-	26.8	-	28.1
% RED	-	40.0*	-	47.4	44.0*	-	43.1	-	-	42.3	42.9	-	-	-	41.8	-	47.1
ISO STATIC LTD																	
% +6.3 mm	-	94.0	-	94.5	94.6	-	95.6	-	-	95.1	93.8	-	-	-	95.0	-	94.4
% -0.5 mm	-	5.0	-	5.1	5.2	-	4.3	-	-	4.8	5.7	-	-	-	4.7	-	5.4
JUMBO LTD																	
% +6.3 mm	-	72.5*	-	-	81.5	-	-	-	-	-	-	-	-	-	-	-	-
% -0.5 mm	-	15.7*	-	-	15.2	-	-	-	-	-	-	-	-	-	-	-	-
SOFTENING T° (°C)	-	1202	-	-	1198	-	-	-	-	-	-	-	-	-	-	-	-

* = AVERAGE OF 2 OR MORE TESTS

♦ = OPTIMUM FIRING

- Moisture level of Peridur green balls slightly higher and bed permeability lower.

- The Peridur dry ball strength was higher than obtained at the laboratory scale due to more compaction occuring in the 1 m diameter disk. However, it was still lower than for bentonite pellets.

- Tumble index 1 % lower.

- Equivalent compressive strength.

- Higher porosity and lower residual magnetite.

- Improvement of about 0.21 % O_2/min in R_{40}

- Unacceptable 30 % swelling.

- Equivalent static LTD results.

The improvement of mixing conditions (test series # 2) along with a slightly higher firing T ° peak resulted in improved balling control and better tumble index. A small improvement was noted in both static and Jumbo dynamic LTD results. The softening test results show that the high T ° properties are not significantly different for Peridur pellets. The very high swelling was confirmed.

In test # 3, the addition rate of Peridur was increased to 0.09 %. The green ball moisture had to be closely controlled to avoid excessive plasticity. No major improvement was observed in pellet quality.

In test # 4, a combination of 0.2 % bentonite and 0.07 % Peridur was used. As observed in the laboratory scale tests, the addition of a small amount of bentonite improved the balling response to moisture fluctuations. No significant improvement was seen in pellet quality under normal or extended firing time.

Test # 8 was performed at a 50 % bentonite substitution ratio. The green ball moisture had to be kept high to ensure good balling control. The dry ball strength decreased. The tumble index was poor and the metallurgical properties showed a compromise between bentonite and Peridur pellets.

In test series # 13, the addition rate of Peridur was lowered to 0.05 % and 0.2 % bentonite was added. The filter cake used was different from the other tests. The carbon content was very low and the total heat content was about 15 % lower in spite of a higher magnetite level. The balling behaviour was good with a satisfactory moisture control. The optimum green ball moisture was 9.3 % which is relatively high and requested some adjustment in the pressure drop during firing. The tumble index was still about 0.5 to 1.0 % lower than bentonite pellets. The compressive strength was better due to lower internal heat (Heat Magnetite Equivalent).

The # 13C was a repetition of the optimum test # 13B with the difference that fired pellets from test # 13B were recycled as the hearth layer of test # 13C. This hearth layer was included in all the samples for the measurement of pellet properties. Because they only account for about 20 % of the production, the recycled pellets did not significantly change the major trends already

observed in Peridur pellet properties. The hearth layer pellets alone exhibited a clear 10 % decrease in compressive strength going from 291 to 262 kg/pellet.

The LTD of hearth layer pellets was measured with a result of 93,3 % + 6,3 mm (6,1 % -0,5 mm) which is lower than for the upper part of the bed.

The new Peridur "DS" was evaluated in test # 11. The binder showed a better water retention capacity (green ball moisture of 9.3 %) but a lower dry ball strength. This confirms the laboratory test results. All the fired pellet properties were similar to those obtained with the Peridur 2.30 except for a further increase in reducibility.

5.3 Effect of various additives on Peridur acid pellets

The impact of a small addition of dolomite, limestone or bauxite on the quality of Peridur acid pellets was evaluated and the results are shown in the first part of tables 6 and 7.

The addition of 0.75 % dolomite to pellets made from 0.07 % Peridur 2.30 (test # 5) resulted in a clear improvement in tumbling strength. A small increase in compressive strength was also observed along with a slight deterioration of the LTD. The R_{40} and swelling were still high.

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TABLE 6

EFFECT OF VARIOUS ADDITIVES - TESTS CONDITIONS

TEST #	5A	5B	6A	6B	9A	9B	10A	10B	17A	17B	12A	12B	16A	16B	15A	15B	14A	14B	14C
	*		*			*	*			*	*			*		*		*	*
TEST DESCRIPTION	0.07 % PER +0.75% DOLO		0.07 % PER +1.5% DOLO		0.07 % PER +0.75% LIM		0.07 % PER +1.5% LIM		0.05 % PER +1.0% LIM		0.07 % PER +1.0% BAUX		0.07 % PER +0.5% BAUX		FLUX. PELL. 0.8% BENT		FLUXED PELLETS. 0.07% PERIDUR		
MIXING PROCEDURE	PER. MIXED WITH DOLO.		PER. MIXED WITH DOLO.		PER. MIXED WITH LIMEST.		PER. MIXED WITH LIMEST.		PER. MIXED WITH LIMEST.		PER. MIXED WITH BAUX.		PER. MIXED WITH BAUX.		NORMAL		PERIDUR MIXED WITH FLUXES		
% HEAT MAG. EQUIV. (%C X 64 +%MAG)	90		92		88		90		81		90		80		80		79		
FILTER CAKE																			
% -325 M	64.8		64.6		65.1		65.3		66.3		64.6		66.4		66.3		65.8		
BLAINE (cm2/g)	1755		1705		1760		1750		1720		1700		1720		1715		1680		
% MAG (Satmagan)	29.1		28.9		28.8		28.6		42.4		28.3		41.9		42.2		42.3		
WET BED (cm)	38.0	38.0	38.0	38.0	38.0	38.0	38.0	38.0	38.0	38.0	38.0	38.0	38.0	38.0	35.6	35.6	36.8	35.6	35.6
HEARTH LAYER (cm)	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
FIRING TIME (min)	41.0	41.0	41.0	41.0	41.0	41.0	41.0	41.0	41.0	41.0	41.0	41.0	41.0	41.0	46.0	46.0	42.2	46.0	46.0
t/day ft2 (G. Balls)	3.10	3.10	3.10	3.10	3.10	3.10	3.10	3.10	3.10	3.10	3.10	3.10	3.10	3.10	2.47	2.47	2.82	2.47	2.47
AIR FLOW (Nm3/m2min)																			
UDD	98	93	100	93	97	94	96	93	99	95	N/A	92	98	101	99	99	97	94	101
F-7	25	22	24	23	25	22	25	22	25	24	N/A	N/A	25	25	28	27	27	26	27
COOLING	104	93	103	94	100	93	98	92	101	99	N/A	89	105	108	121	122	109	115	118
FIRING T° MAX (°C)	1260	1260	1260	1260	1260	1260	1260	1260	1260	1290	1260	1260	1260	1290	1315	1315	1290	1315	1315
INTERFACE T° (°C)	1330	1255	1305	1275	1320	1310	1305	1280	1295	1260	1315	1165	1300	1320	1260	1240	1225	1250	1260
MIN. AT T° > 1200 °C	4.1	0.6	2.9	1.4	3.5	2.7	2.9	1.8	3.0	2.6	3.0	0.0	2.6	3.9	3.0	1.6	1.5	3.3	4.3
GAS T° (°C) WB @ 30	500	295	450	350	415	320	370	330	395	380	305	215	430	480	615	560	450	605	660

* = OPTIMUM FIRING

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TABLE 7

EFFECT OF VARIOUS ADDITIVES - TESTS RESULTS

TEST #	5A +	5B	6A +	6B	9A	9B +	10A +	10B	17A +	17B	12A +	12B	16A +	16B	15A	15B +	14A	14B +	14C +
TEST DESCRIPTION	0.07 % PER +0.75% DOLO		0.07 % PER +1.5% DOLO		0.07 % PER +0.75% LIM		0.07 % PER +1.5% LIM		0.05 % PER +1.0% LIM		0.07 % PER +1.0% BAUX		0.07 % PER +0.5% BAUX		FLUX. PELL. 0.8% BENT		FLUXED PELLETS. 0.07% PERIDUR		
GREEN BALLS																			
% H2O	8.9		9.0		8.9		8.9		8.8		9.2		8.9		9.2		9.2		
DROPS	17		19		20		20		15		20		19		18		19		
WET STRENGTH (Kg)	1.5		1.6		1.4		1.6		1.4		1.6		1.6		1.4		1.6		
DRY STRENGTH (Kg)	4.7		4.4		4.6		4.7		3.5		4.6		4.6		5.1		4.3		
FIRED PELLETS																			
ASTM TUMBLE																			
% +6.3 mm	96.2	94.9	95.7	95.7	95.8	96.1	95.7	95.6	95.4	95.7	95.6	91.0	95.7	96.0	96.4	96.3	91.1	96.2	96.3
% -0.5 mm	3.8	5.0	4.1	4.1	4.1	3.8	4.2	4.3	4.5	4.2	4.3	8.8	4.2	3.8	3.3	3.3	8.7	3.8	3.6
STRENGTH (Kg)																			
$\bar{x}$	284	267	269	266	297	291	275	290	310	307	276	240	270	302	283	266	237	272	266
σ n-1	42	58	42	57	55	60	55	67	66	78	62	95	55	71	69	67	67	59	71
TOP OF BED	282	277	277	296	275	307	279	294	338	339	278	290	267	291	230	267	249	269	289
MIDDLE	277	251	263	262	290	294	283	299	314	311	285	285	276	325	290	298	260	292	284
BOTTOM	294	272	266	242	327	274	262	278	278	270	264	145	268	292	329	274	203	255	259
HEARTH LAYER	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	228	-	-	232
POROSITY (%)	28.2	-	28.5	28.0	-	28.0	28.0	-	27.4	27.3	27.5	-	27.3	26.5	-	26.0	-	-	28.0
SATMAGAN (%)	0.8	-	0.9	0.9	-	0.9	1.0	-	0.4	0.5	0.8	-	0.8	1.6	-	10.0	-	-	6.4
ISO R40 (%O2/min)	0.76	-	0.72	0.82	-	0.68	0.71	-	0.70	0.74	0.54	-	0.51	0.52	-	0.92	-	-	1.12
ISO SWELLING																			
% VOL	27.5	-	24.7	25.6	-	29.5	25.0*	-	30.3	26.9	19.8*	-	19.1	19.6	-	10.0	-	-	9.7
% RED	43.5	-	44.0	42.1	-	45.7	41.2*	-	46.5	46.1	38.3*	-	40.2	39.1	-	51.4	-	-	56.9
ISO STATIC LTD																			
% +6.3 mm	93.4	-	93.3	91.3	-	95.3	96.8	-	96.3	96.4	94.3	-	95.2	95.3	-	93.1*	-	-	96.3*
% -0.5 mm	5.6	-	6.5	8.1	-	4.5	3.1	-	3.5	3.2	5.1	-	4.7	4.0	-	5.3*	-	-	3.4*
JUMBO LTD																			
% +6.3 mm	-	-	64.4*	-	-	-	92.7*	-	-	-	-	-	-	-	-	81.4	-	-	85.2
% -0.5 mm	-	-	29.4*	-	-	-	6.5*	-	-	-	-	-	-	-	-	15.5	-	-	11.2
SOFTENING T° (°C)	-	-	1198	-	-	-	1198	-	-	-	-	-	-	-	-	1320	-	-	1326

* = AVERAGE OF 2 OR MORE TESTS

+ = OPTIMUM FIRING

In test # 6 the dolomite addition rate was increased to 1.5 %. The tumble index and compressive strength were comparable to values obtained on Peridur pellets made without dolomite. A clear decrease in swelling was obtained but it was not sufficient to reach the acceptable level of 20 %. The Jumbo LTD test results were very poor. Further investigation is required before to consider dolomite as an acceptable additive to Peridur acid pellets.

The addition of 0.75 % limestone to Peridur pellets (test # 9) resulted in good tumble index, higher compressive strength and better LTD. The reducibility and swelling were still high.

The addition of limestone was increased to 1.5 % in test # 10. As observed with dolomite pellets the tumble index decreased from 96.1 to 95.7 and the compressive strength from 291 to 275 kg. The swelling decreased to 25 %. The static and Jumbo dynamic LTD results were excellent and much better than the reference bentonite pellets. (test # 7 of table 5)

In test # 17 the addition rates of both Peridur and limestone were lowered to respectively 0.05 % and 1.0 %. The tumble index was about 1 % lower than for bentonite pellets. The tumble slightly improved with a higher firing T ° (test # 17B). The compressive strength was more than 300 kg due to the combined effect of limestone and low internal heat (H.M.E.). The R_{40} and LTD were still very good but the swelling increased significantly.

The addition of limestone proved to have a good potential to improve the quality of Peridur acid pellets and should

also be considered for bentonite pellets. The optimisation of the limestone addition rate and firing conditions requires further testing.

Test # 12 shows the effect of a 1 % bauxite addition to Peridur pellets. The tumble index was low at 95.6 % and no impact was observed on compressive strength. The reducibility decreased drastically to 0.54 % O_2/min which is comparable to bentonite pellets. The swelling also decreased to an acceptable level of 19.8 %. The LTD results were equivalent to bentonite pellets.

In test # 16 the addition rate of bauxite was decreased to 0.5 %. The results were similar to test # 12 except for a higher pellet strength due to a lower internal heat content. A higher firing T ° also improved the tumble index (test # 16B).

The addition of bauxite has an effect comparable to bentonite on high T ° properties of fired pellets. This effect is believed to be due to the presence of alumina (Al_2O_3) which increases the kinetic of fayalite formation. The fayalite is a low melting phase which inhibates the reduction process.

5.4 Further considerations on swelling of acid pellets

When comparing the swelling behaviour of various types of pellets, the degree of reduction reached after the standard reduction period of 60 minutes should be taken into consideration.

In particular, the better reducibility of Peridur pellets translates in a high degree of reduction reached in the ISO swelling test as compared to bentonite pellets.

In order to have a better picture of the swelling behaviour of Peridur and bentonite acid pellets we have modified the duration of the reduction period. The pellet swelling was measured after 30, 60, 75, 90 and 120 minutes of reduction and the results are shown in figures 1 and 2.

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FIGURE 1: SWELLING BEHAVIOUR OF PERIDUR AND BENTONITE PELLETS
% SWELLING VS TIME

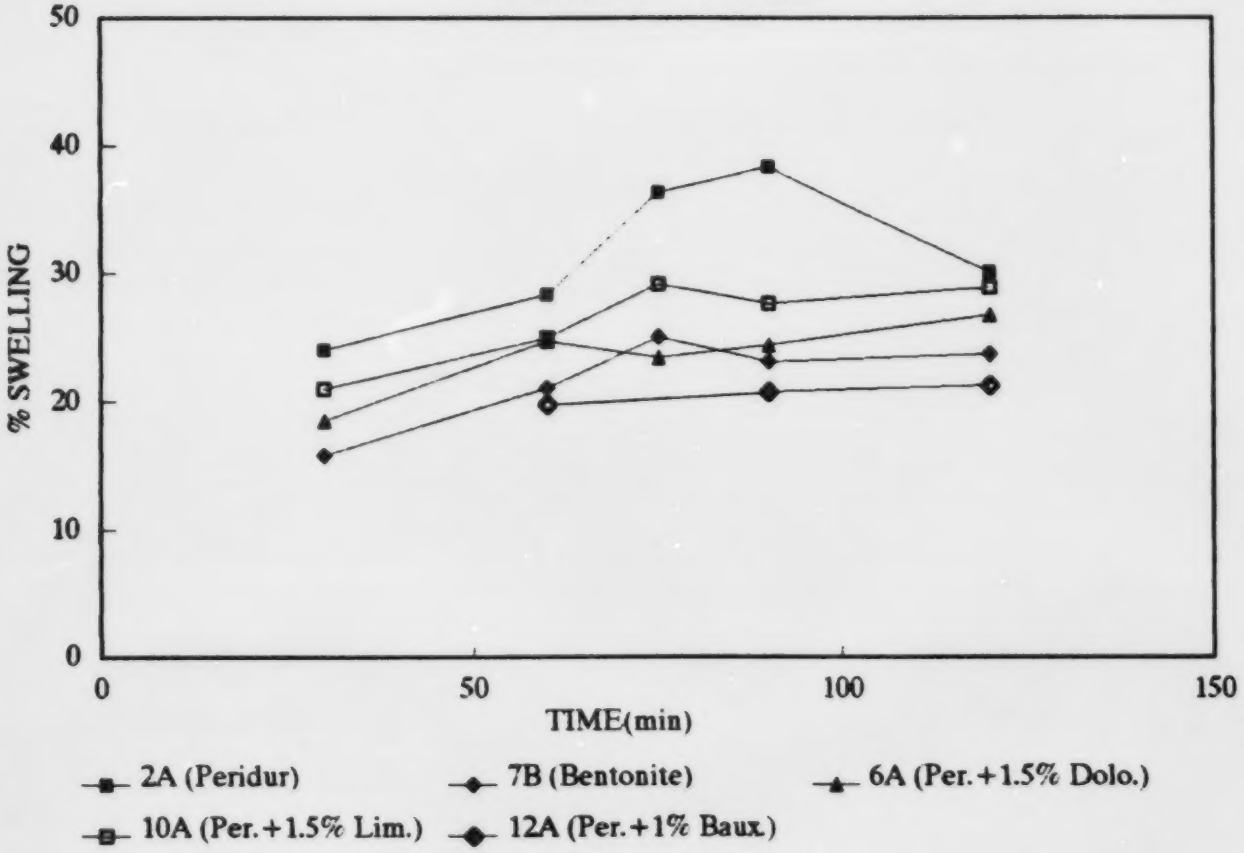
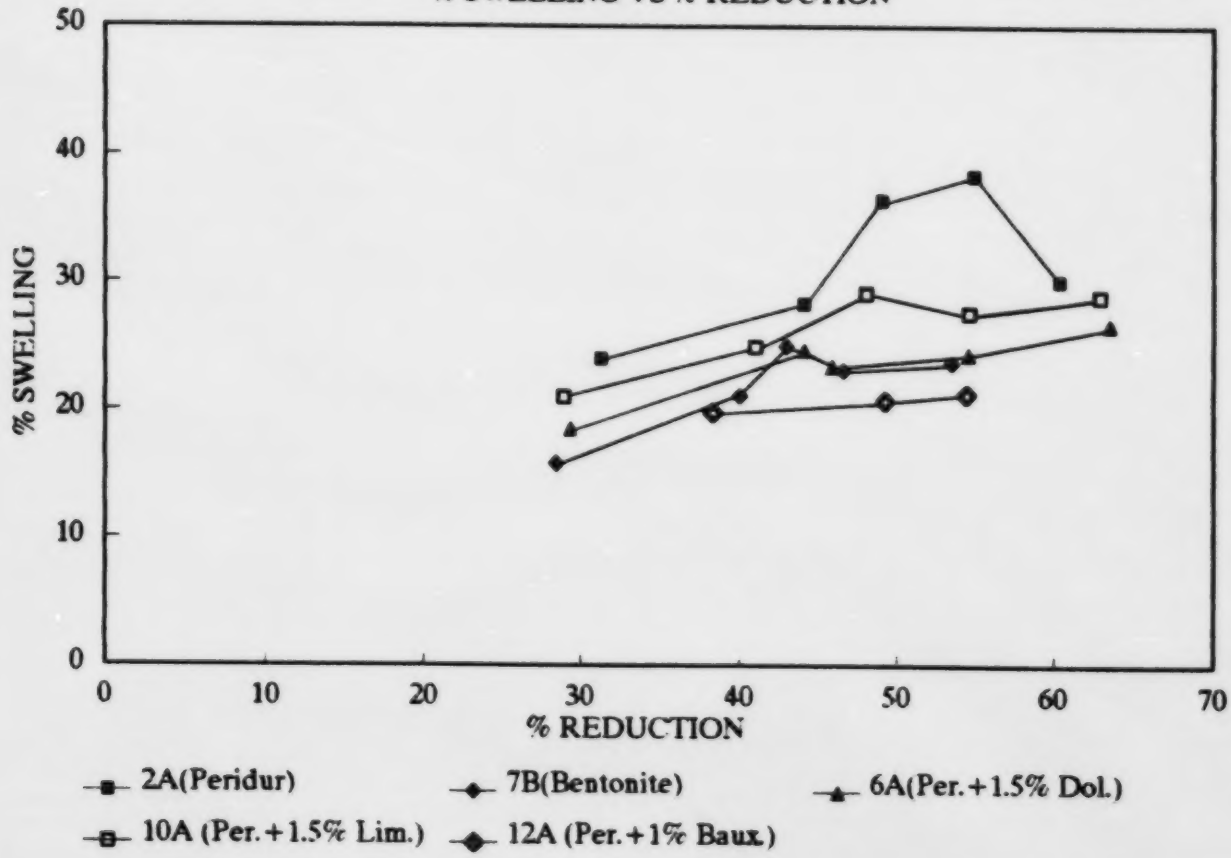


FIGURE 2: SWELLING BEHAVIOUR OF PERIDUR AND BENTONITE PELLETS
% SWELLING VS % REDUCTION



It is clear that the high swelling of Peridur pellets is not only because of their higher reducibility.

All the additives tested have decreased the swelling of Peridur acid pellets. The best additive is clearly bauxite followed by dolomite and finally limestone.

5.5 Peridur Vs bentonite fluxed pellets

The test conditions and results are summarized in the last part of tables 6 and 7 under test series # 14 (Peridur) and 15 (bentonite). In these tests, 7.5 % dolomite and 3.5 % limestone (3.0 % for Peridur pellets) were added.

The filter cake having a low internal heat content (about 80 % H.M.E.) was used. Tests # 15A, 15B, 14B and 14C were done under the same firing conditions. The hearth layers of test # 15B and 14C were made using the pellets from tests # 15A and 14B respectively in order to evaluate the effect of recycling on pellet quality.

The comparison of Peridur and bentonite fluxed pellets leads to the following remarks :

- A very slight deterioration of the tumble index for Peridur pellets (less than 0.5 %).

- Equivalent compressive strength. The hearth layer of both types of pellets showed a compressive strength about 15 to 20 % lower than pellets from the upper part of the bed.

- Porosity of Peridur pellets was higher and Satmagan was lower (as for acid pellets).

- R_{40} was 0.20 % O_2/min higher for Peridur (same as for acid pellets).

- Swelling was equivalent for both types of pellets.

- Static and Jumbo dynamic LTD results were better for Peridur pellets. The static LTD results on hearth layer pellets were respectively 87.0 and 93.3 for bentonite and Peridur. This confirms the better performance of Peridur pellets.

- Softening T ° were equivalent.

Table 8 details the results obtained in Jumbo dynamic LTD and softening T ° tests.

In summary, except for a slight deterioration of the tumble index, the quality of Peridur fluxed pellets was superior to bentonite fluxed pellets.

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TABLE 8

JUMBO LTD AND SOFTENING T° - TESTS RESULTS

TEST #	TEST DESCRIPTION	JUMBO LTD +6.3 mm	JUMBO LTD +3.15 mm	JUMBO LTD -0.5 mm	SOFTENING T° (% CONTRACTION Va °C) 10	20	30	40	50	55	FDR**
7B	REF. TEST 0.8 % BENT	72.5*	82.6*	15.7*	1092	1132	1158	1178	1202	1223	68.8
2A	0.07 % PER	81.5*	84.4*	15.2*	1091	1130	1155	1174	1198	1216	68.0
6A	0.07 % PER 1.5 % DOLO.	64.4*	69.0*	29.4*	1095	1125	1150	1173	1198	1219	67.7
10A	0.07 % PER 1.5% LIMEST.	92.7*	93.5*	6.5*	1103	1133	1147	1167	1198	1228	68.7
15B	FLUXED PELL. 0.8% BENT	81.4	83.7	15.5	1145	1186	1225	1262	1320	1348	79.2
14C	FLUXED PELL. 0.07 % PER	85.2	88.0	11.2	1148	1194	1225	1269	1326	1358	85.3

* AVERAGE OF 2 OR MORE TESTS.

** FDR = FINAL DEGREE OF REDUCTION (AT 55% CONTRACTION).

6. COLLABORATION

The author would like to mention the contribution of the following pilot plant employees for the realization of the testwork and the preparation of this report :

Jean-Louis Blais, tech. Sp. (Group leader)
Jean-Luc Latulippe, tech.
Claude Gilbert, tech.
Edouard Chrétien, tech. Sp.
Michel Garant, Jr. Eng.
Clerical staff

Appendix 1

Detailed firing conditions for all the tests

DETAILED FIRING CONDITIONS

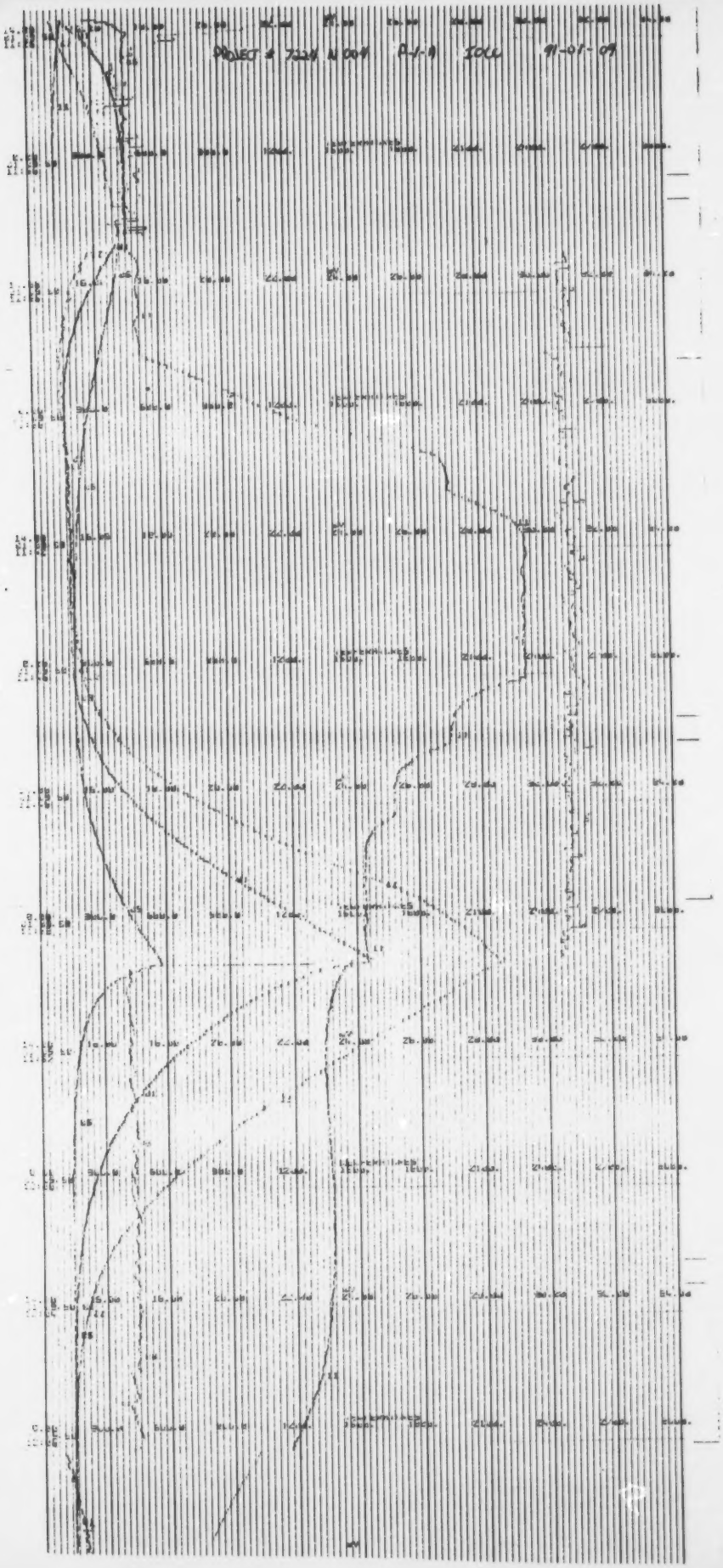
TEST #	CYCLE TIME (min)	BED HEIGHT (cm)	t/day ft2 (Kg)	UDD TWB	DDD 3.5	PH 2.5	F-1 2	F-2 2	F-3 2	F-4 2	F-5 2	F-6 2	F-7 5	COOLING 16	ΔP ("H2O) UDD/FIR./COOL.
1A	41.0	38.0	3.10	230	260	760	1065	1260	1260	1260	1080	930	845	AMB	18/16/18
1B	41.0	38.0	3.10	= 1A WITH ΔP INCREASED BY 2 "H2O											20/18/20
2A	41.0	38.0	3.10	= 1B WITH				1275	1275	1275					20/18/20
2B	41.0	38.0	3.10	= 1A											18/16/18
3A	41.0	38.0	3.10	= 1B											20/18/20
3B	41.0	38.0	3.10	= 1A											18/16/18
4A	41.0	38.0	3.10	= 1B											20/18/20
4B	43.0	38.0	2.96	= 1A WITH 43'00 CYCLE TIME (SMOOTER FIRING)											18/16/18
5A	41.0	38.0	3.10	= 1B											20/18/20
5B	41.0	38.0	3.10	= 1A											18/16/18
6A	41.0	38.0	3.10	= 1B											20/18/20
6B	41.0	38.0	3.10	= 1A											18/16/18
7A	41.0	38.0	3.10	= 1A											18/16/18
7B	41.0	38.0	3.10	= 1B											20/18/20
8A	41.0	38.0	3.10	= 1B											20/18/20
8B	43.0	38.0	2.96	= 1B WITH 43'00 CYCLE TIME											20/18/20
9A	41.0	38.0	3.10	= 1B											20/18/20
9B	41.0	38.0	3.10	= 1A											18/16/18
10A	41.0	38.0	3.10	= 1B											20/18/20
10B	41.0	38.0	3.10	= 1A											18/16/18
11A	41.0	38.0	3.10	= 1B											20/18/20
11B	43.0	38.0	2.96	= 1B WITH 43'00 CYCLE TIME											20/18/20
12A	41.0	38.0	3.10	= 1B											20/18/20
12B	41.0	38.0	3.10	= 1A											18/16/18
13A	41.0	38.0	3.10	= 1B											20/18/20
13B	41.0	38.0	3.10	= 1B WITH ΔP INCREASED TO 20 "H2O											20/20/20
13C	41.0	38.0	3.10	= 13B WITH HEARTH LAYER MADE FROM 13B											20/20/20
14A	42.2	36.8	2.82	230	260	760	1150	1290	1290	1290	1080	925	845	AMB	20/18/20
14B	46.0	35.6	2.47	250	260	730	1065	1260	1315	1315	1275	1150	925	AMB	20/18/20
14C	46.0	35.6	2.47	= 14B WITH HEARTH LAYER MADE FROM 14B											20/18/20
15A	46.0	35.6	2.47	= 14B											20/18/20
15B	46.0	35.6	2.47	= 15A WITH HEARTH LAYER MADE FROM 15A											20/18/20
16A	41.0	38.0	3.10	= 1B											20/18/20
16B	41.0	38.0	3.10	= 1B WITH			1120	1290	1290	1290	1120	980	925		20/18/20
17A	41.0	38.0	3.10	= 1B											20/18/20
17B	41.0	38.0	3.10	= 1B WITH			1175	1290	1290	1290	1205	1120	980		20/18/20

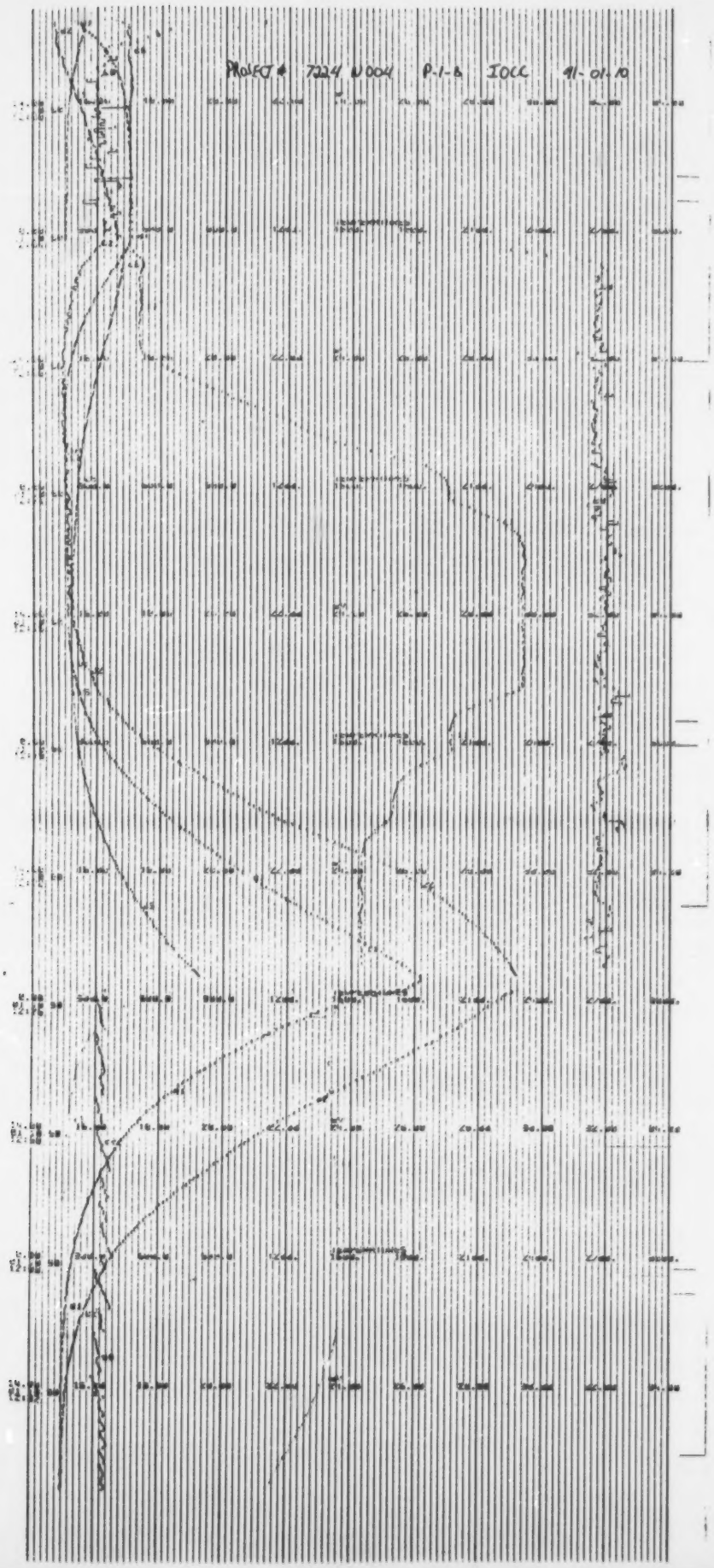
Appendix 2

Firing temperature curves

* T° scale linear from 0 to 3000 °F

For 11A to 13C T/C#	All other tests T/C#	
# 07	# 01:	Hearth layer (center of the layer)
# 08	# 02:	Bottom of the bed (1/2" above interface)
N/A	# 03:	Center of the green bed
N/A	# 04:	Top of the bed (1" in the bed)
# 11	# 05:	Gas T° under the bed (inlet gas for UDD and cooling and outlet for the others)
# 13	# 11:	Gas T° above the bed (outlet gas for UDD and cooling and inlet for the others)
# 12	# 08:	Pressure drop accross the bed (linear scale from -25 to +25 "H_2O)


PROJECT # 7224 N 004 A-1-1 ICU 91-01-09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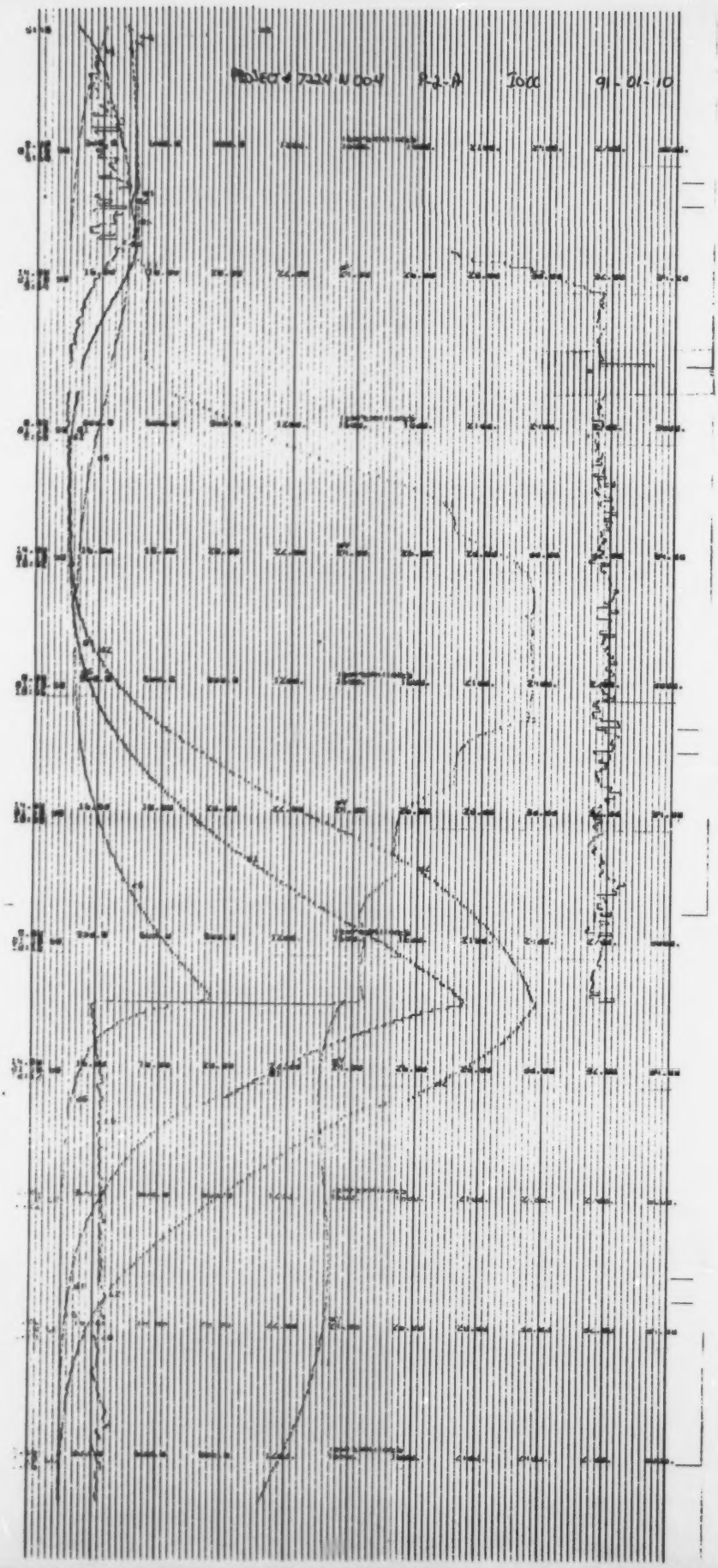
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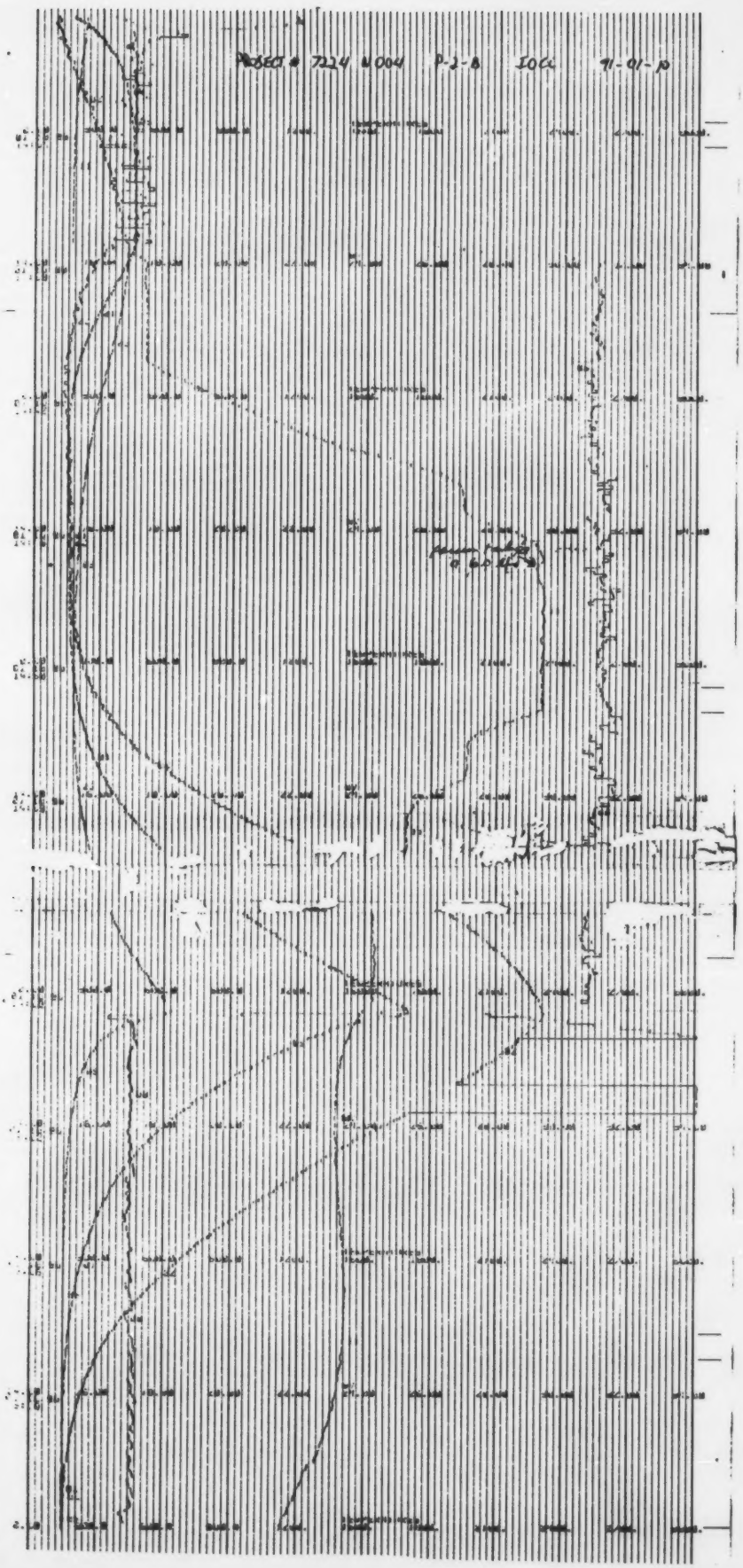
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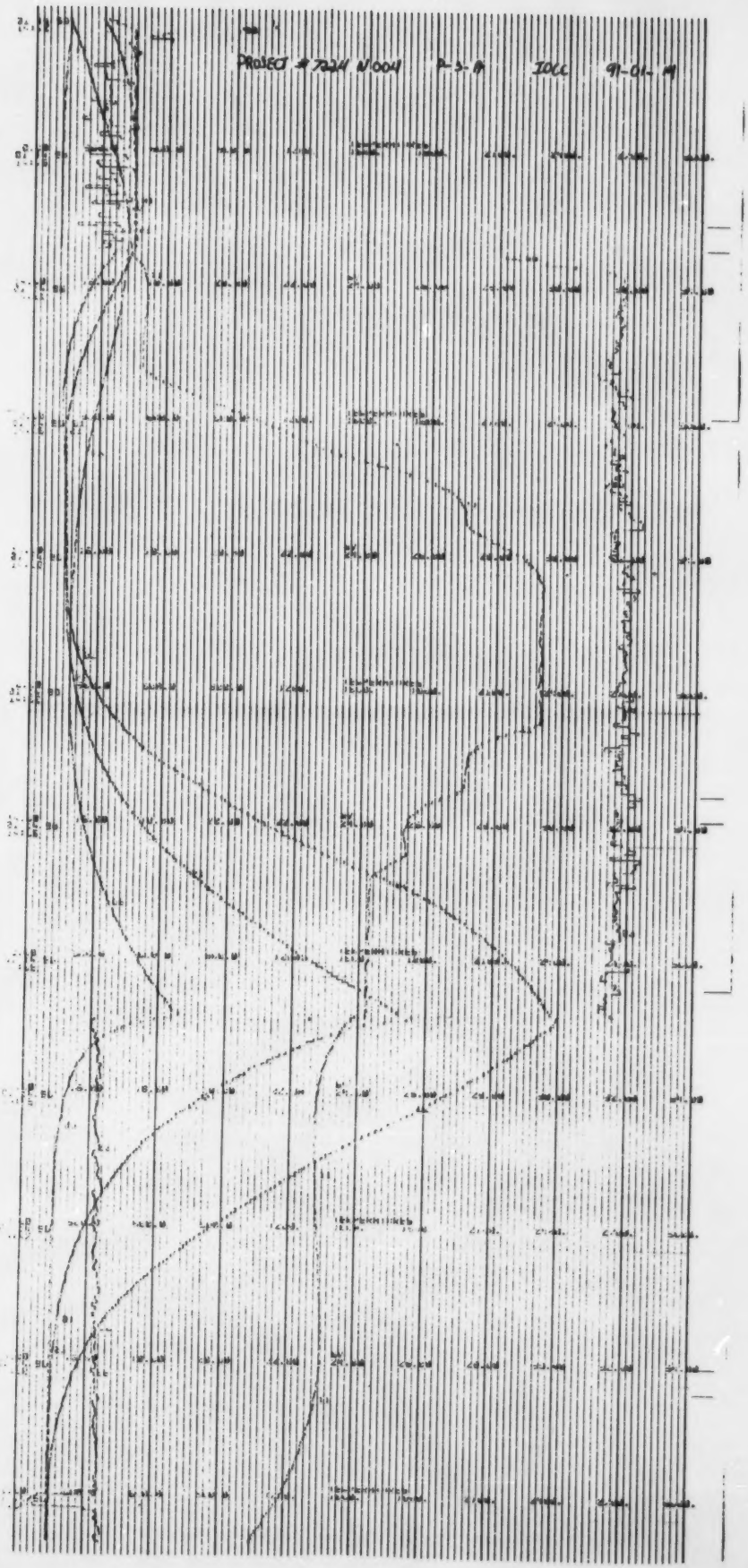
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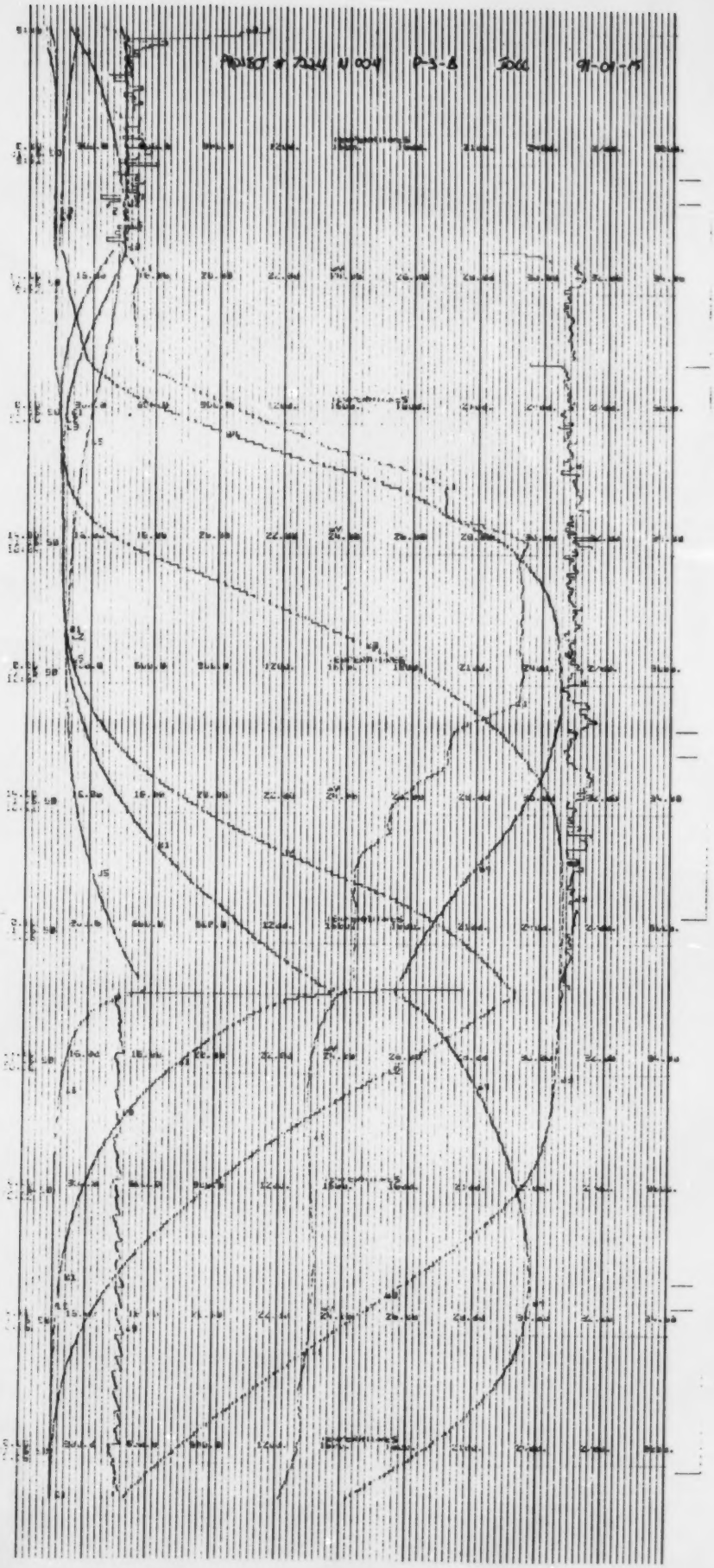

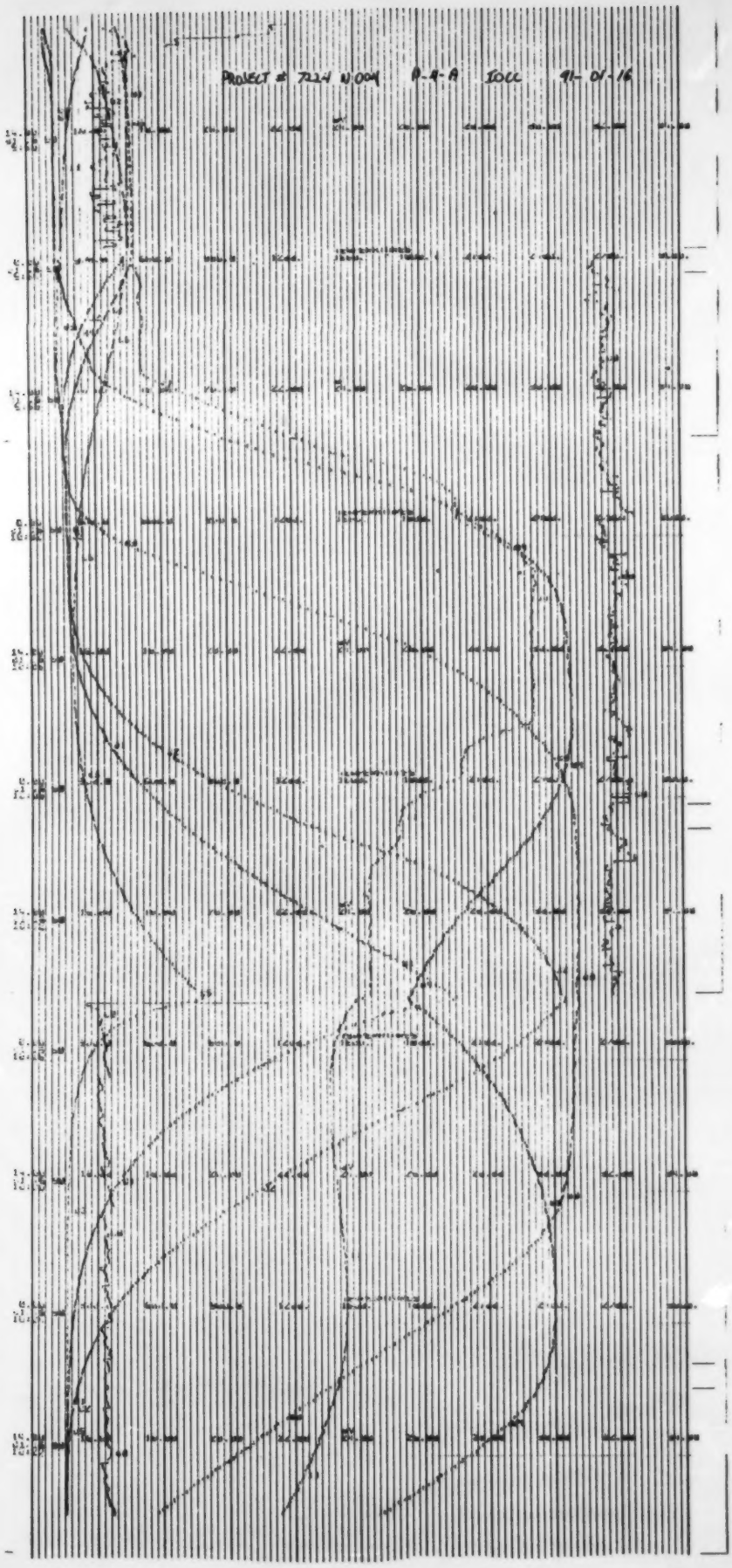
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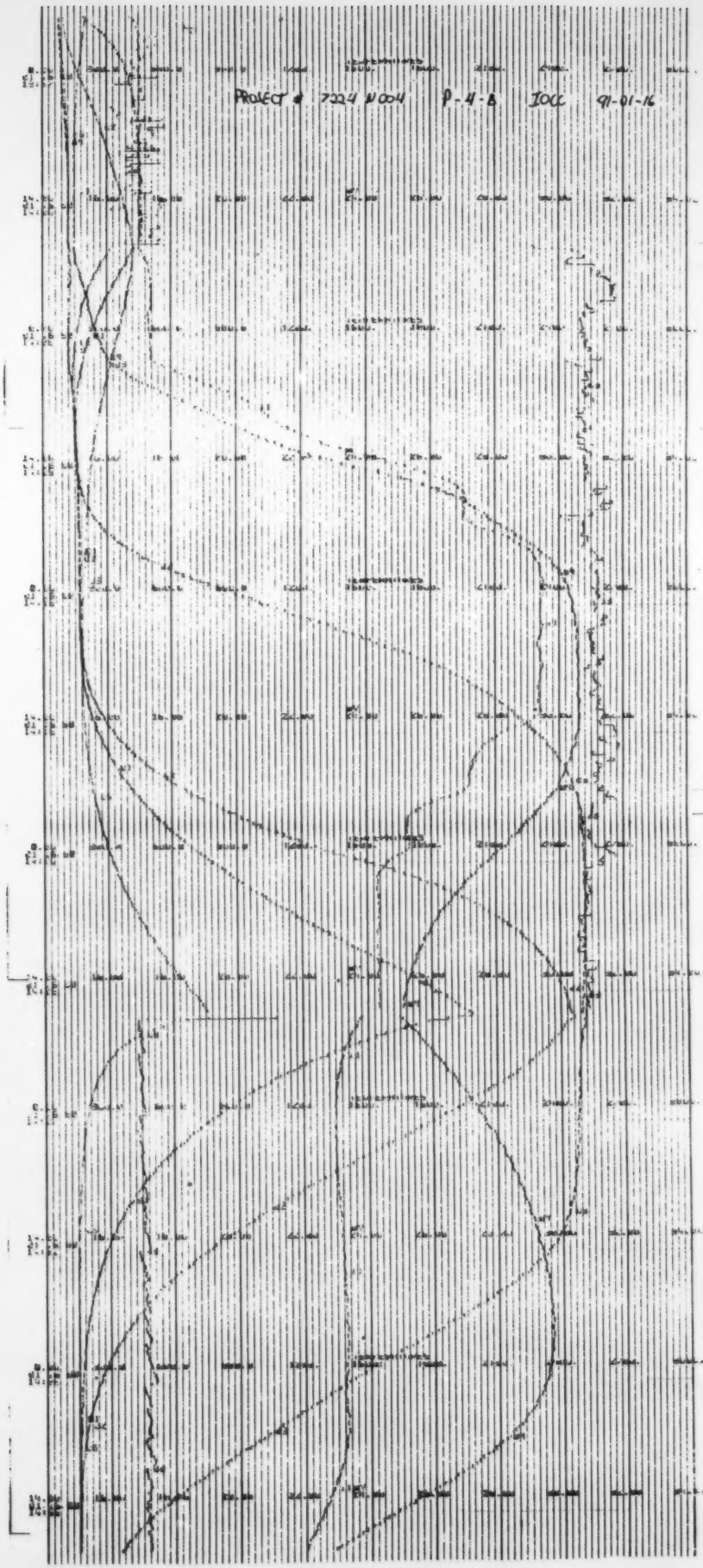
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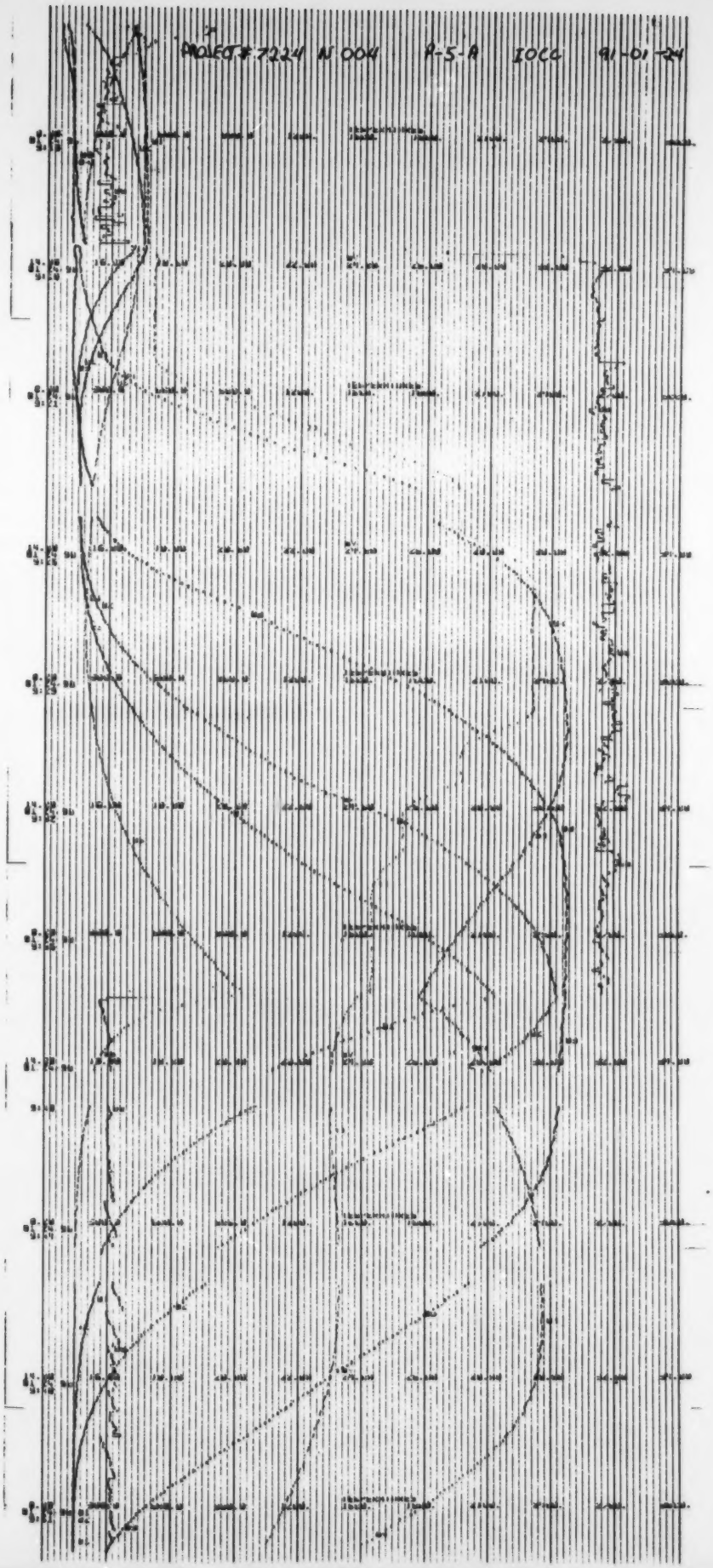
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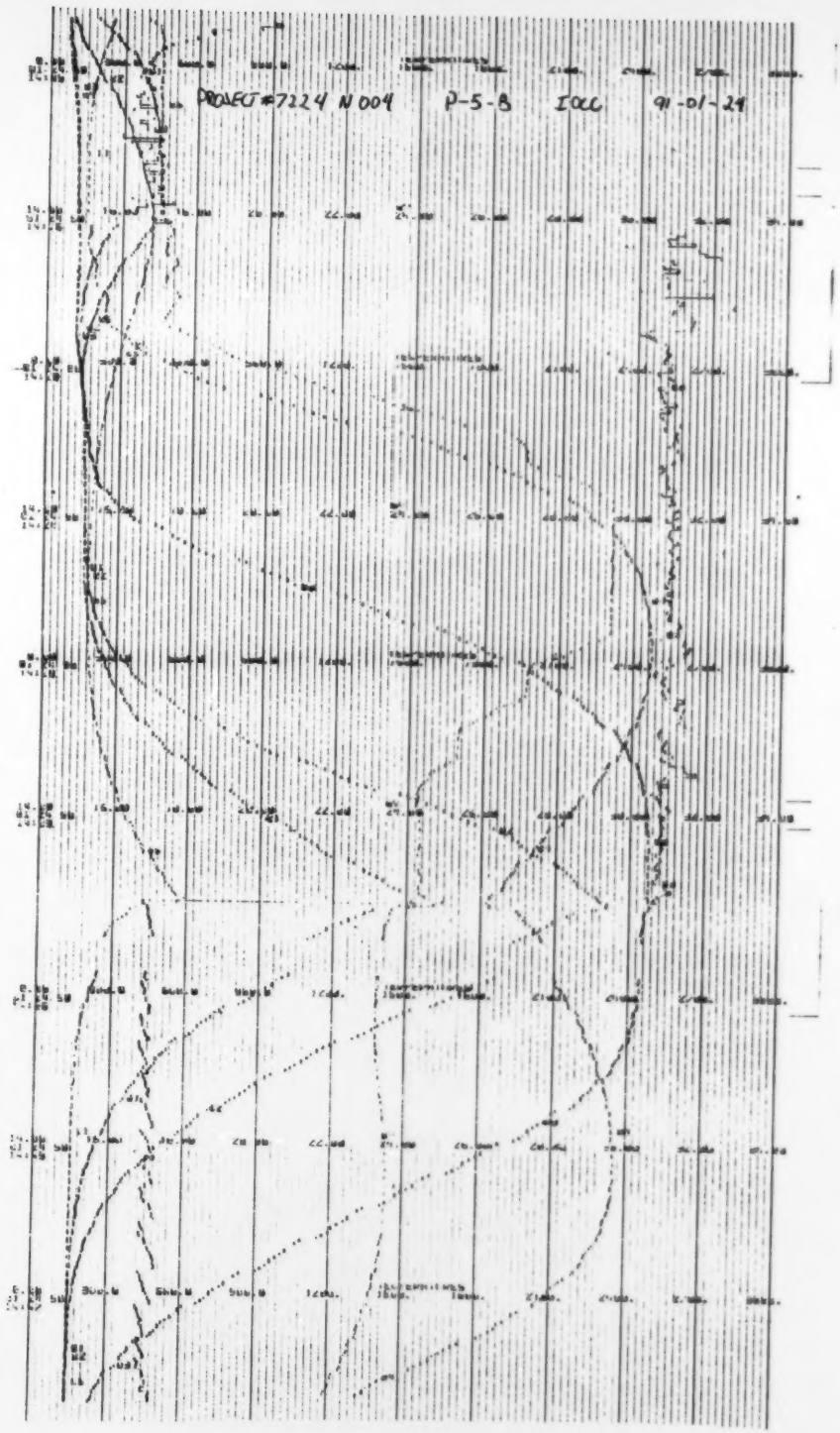
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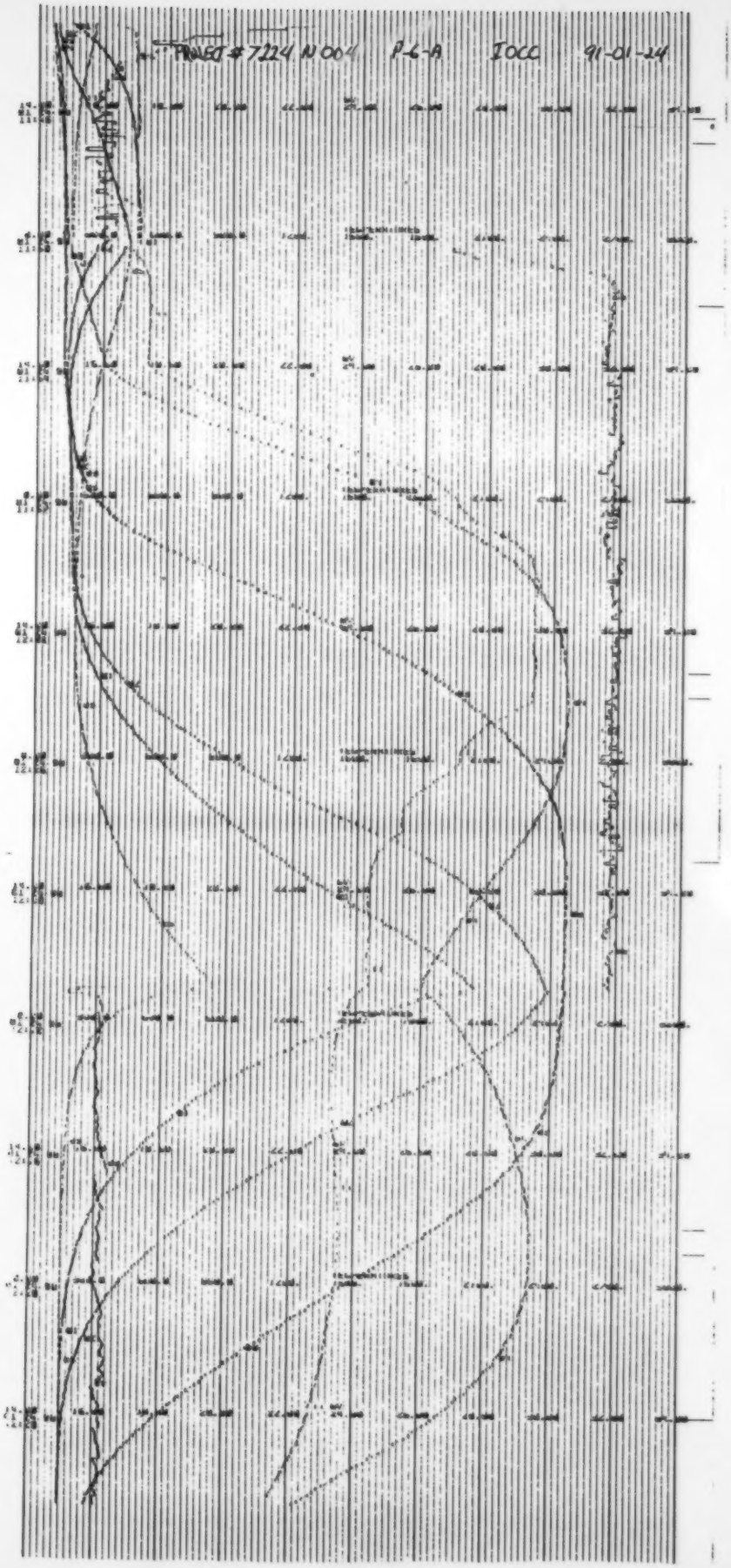
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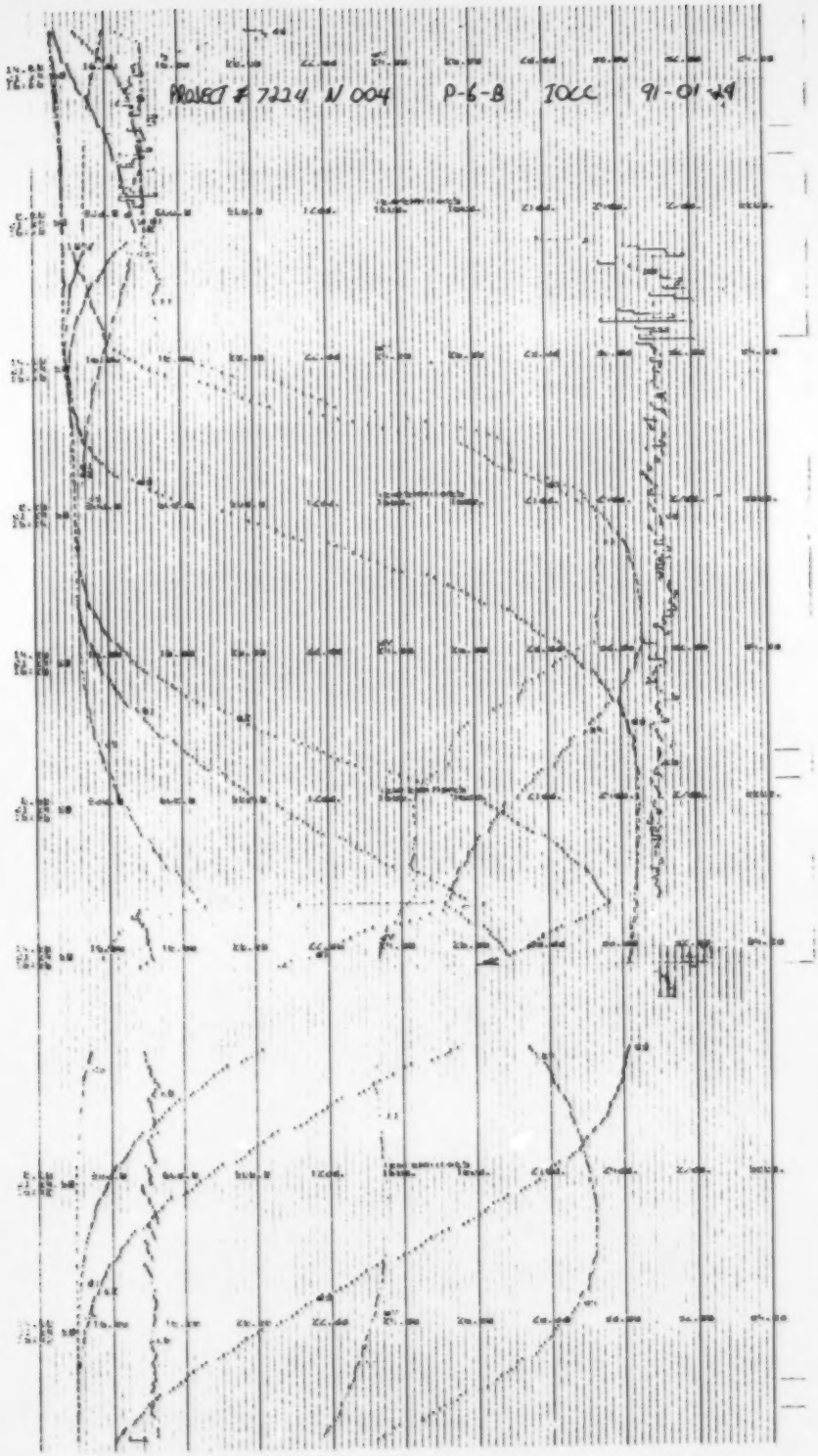
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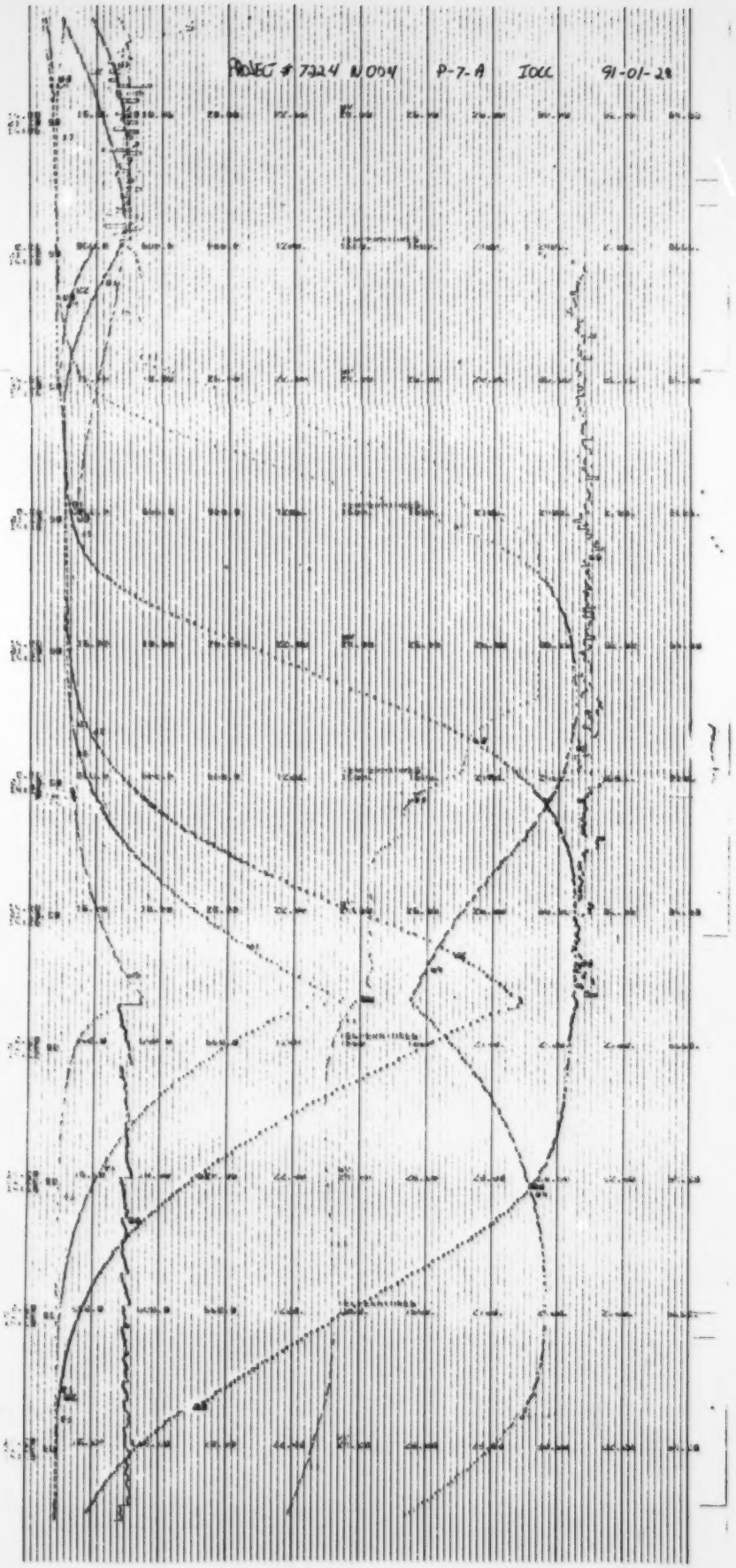
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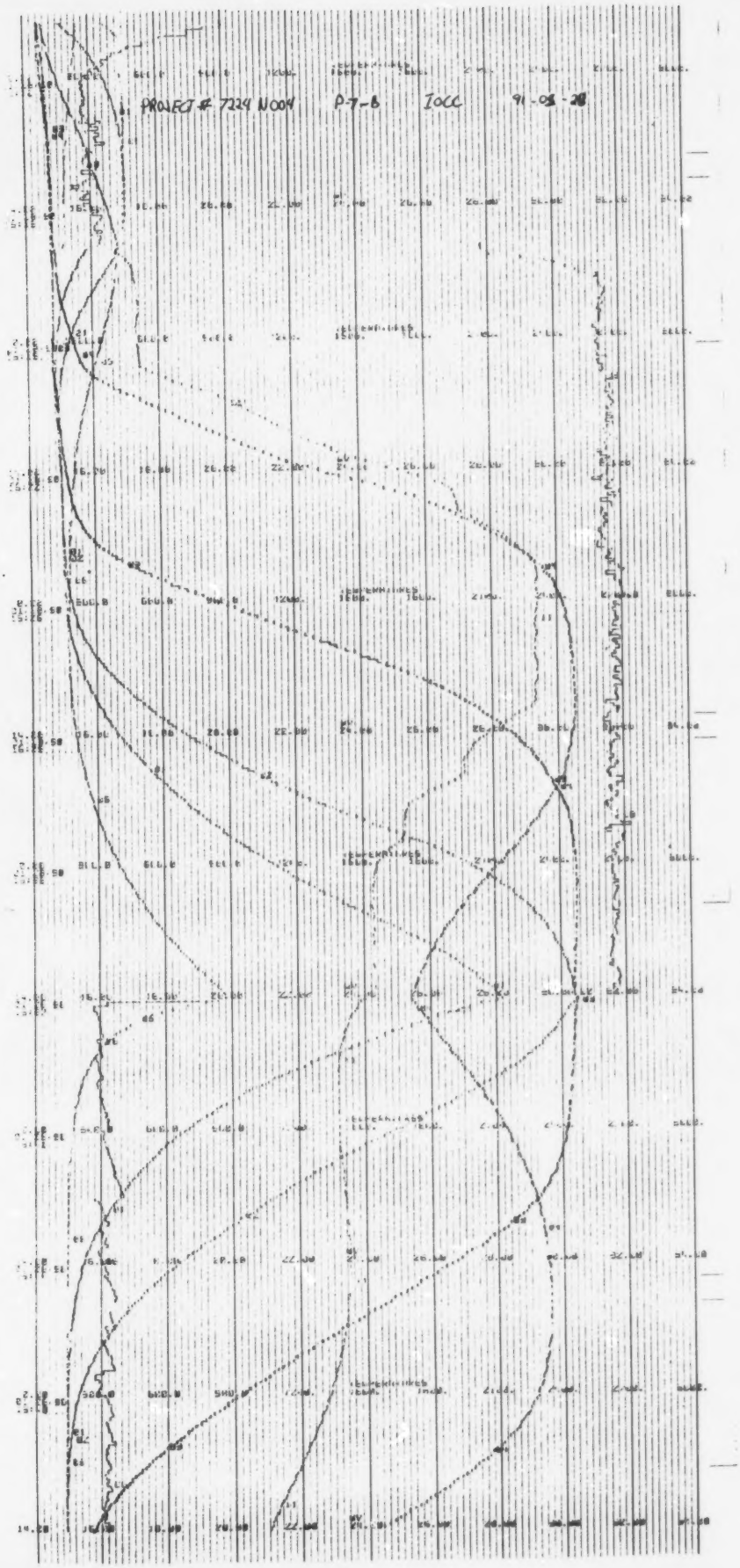
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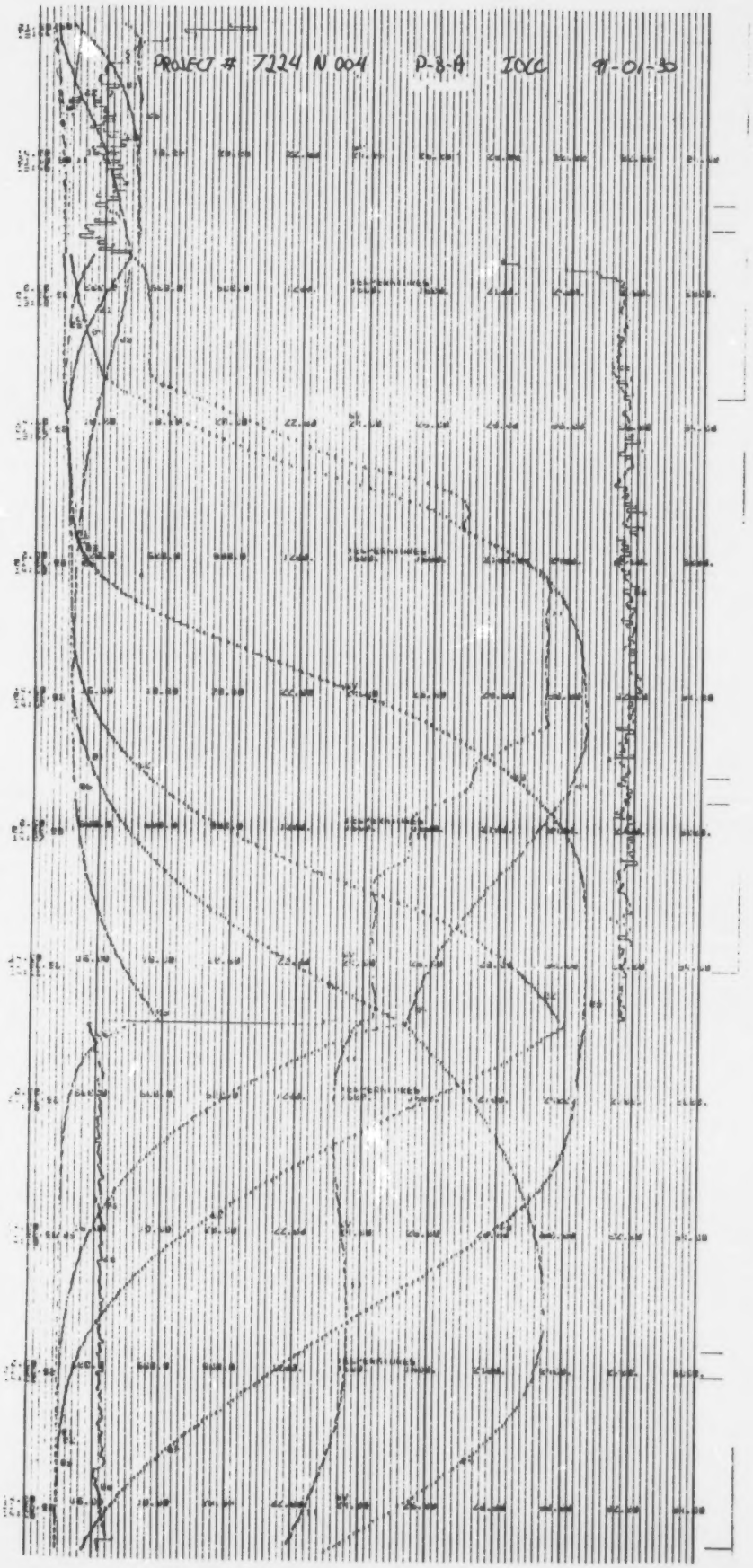
P-7-B
IOCC
91-08-28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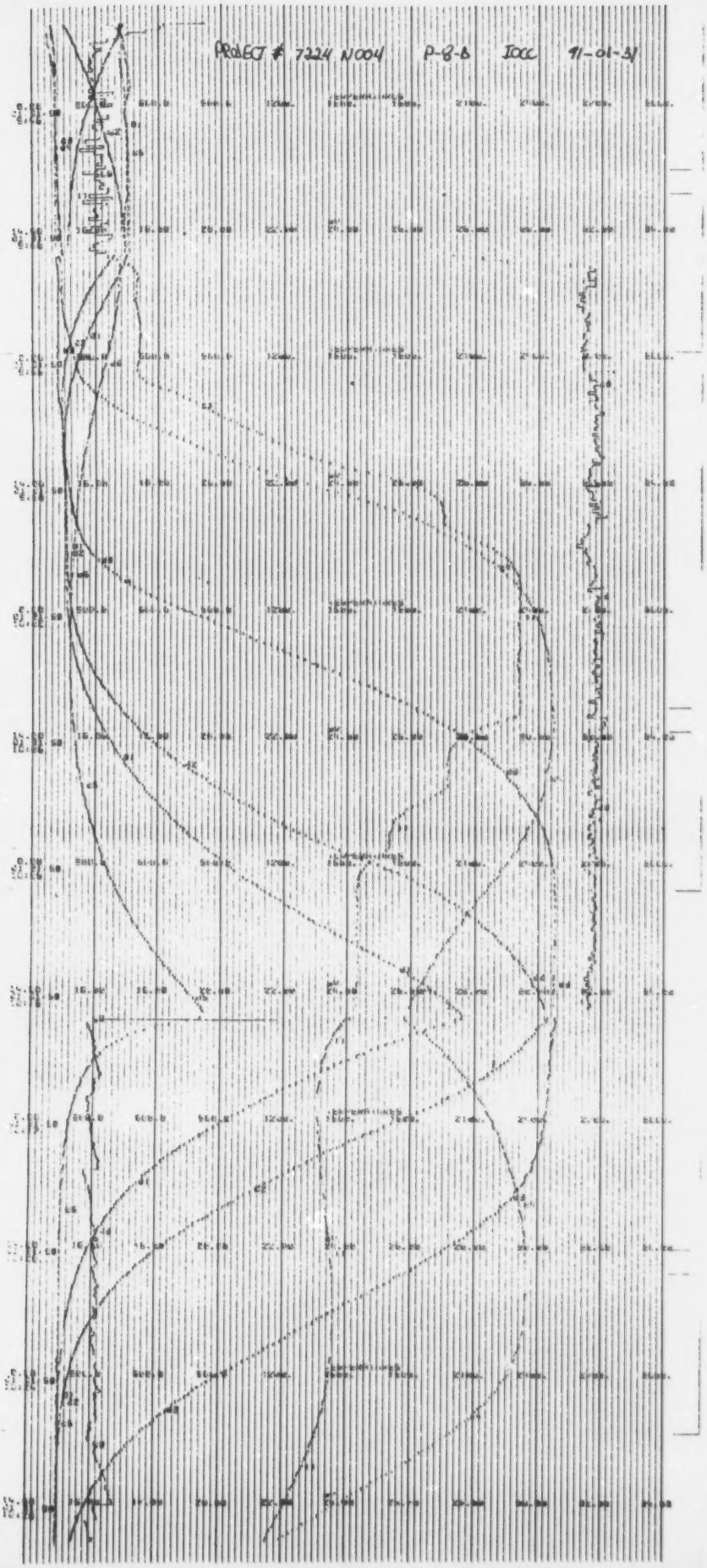
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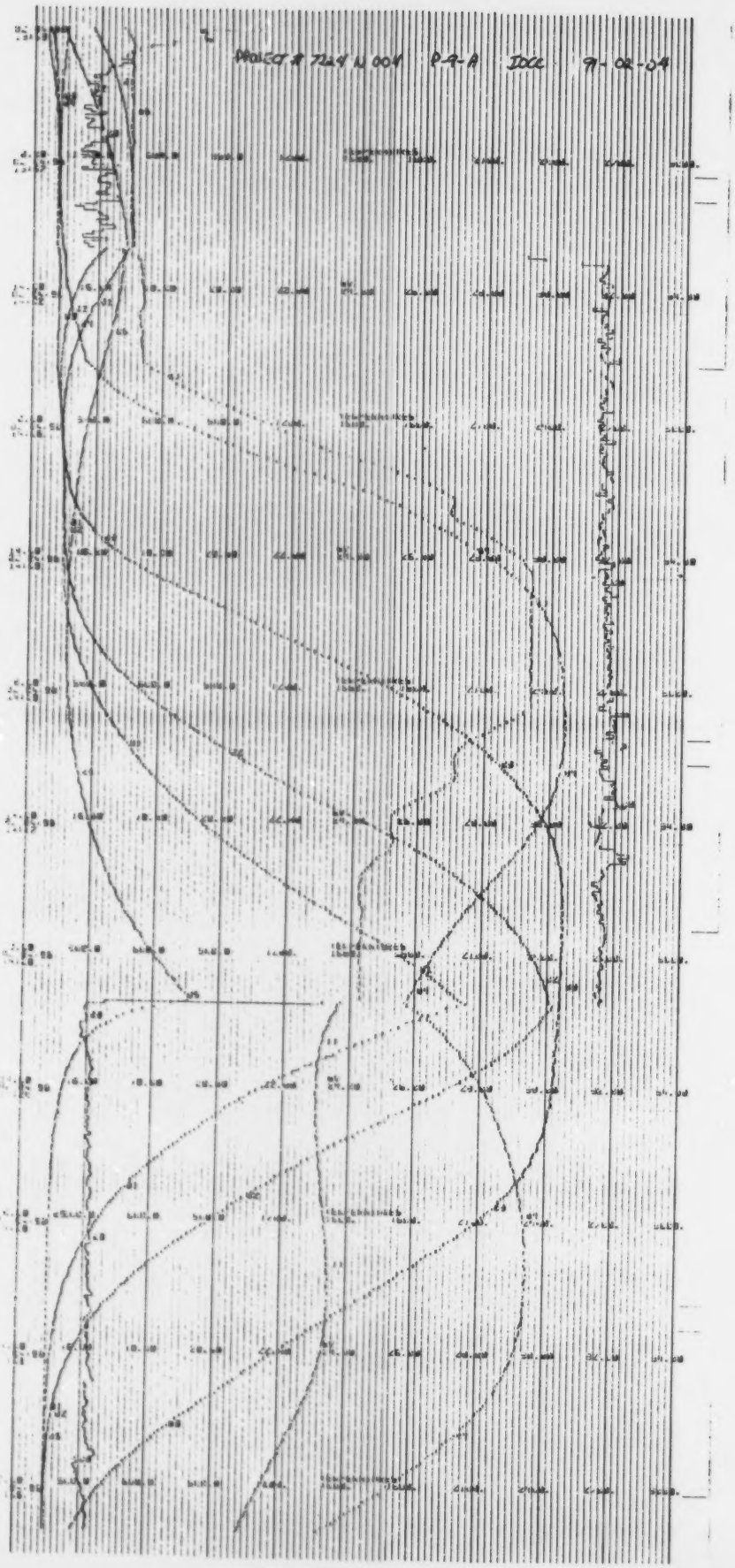
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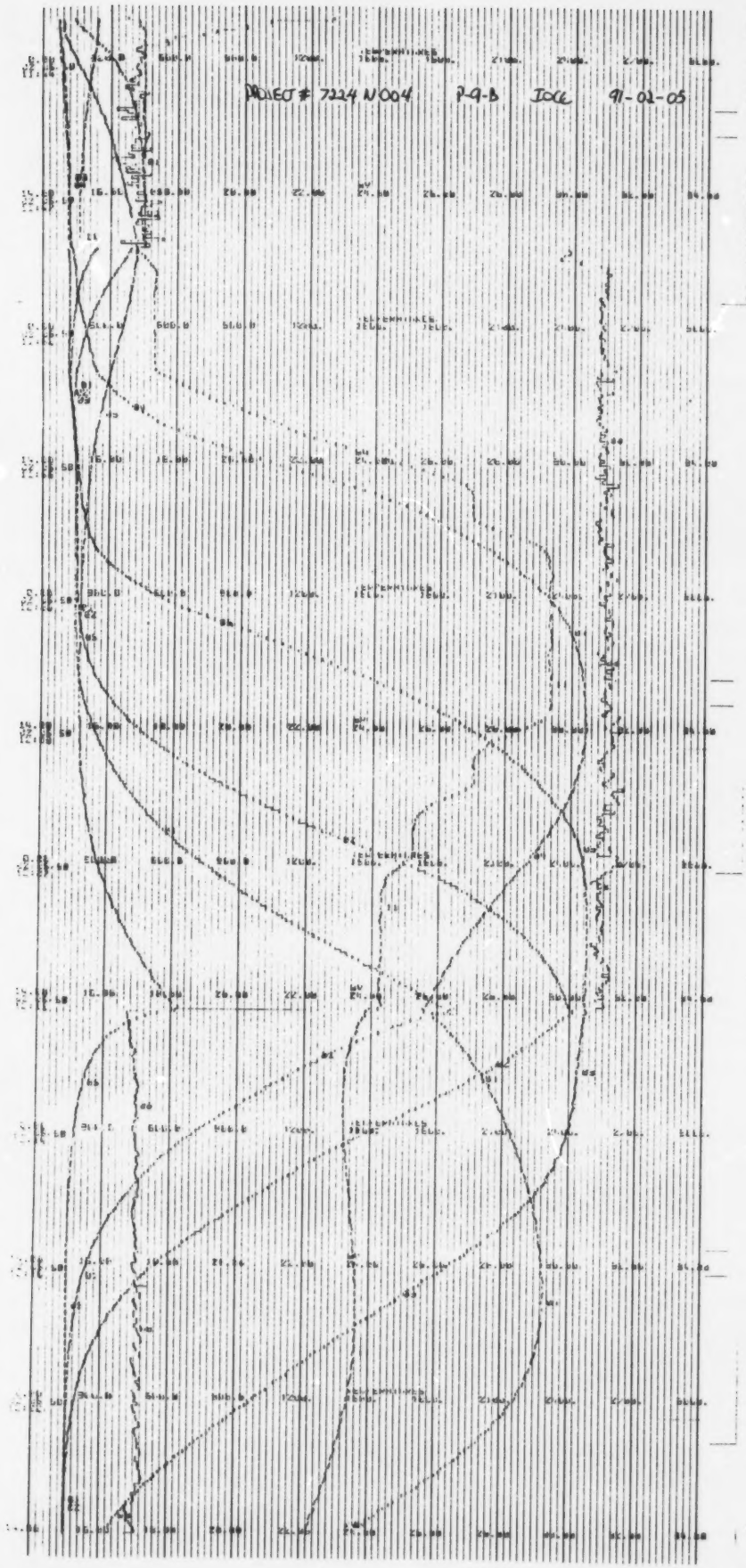
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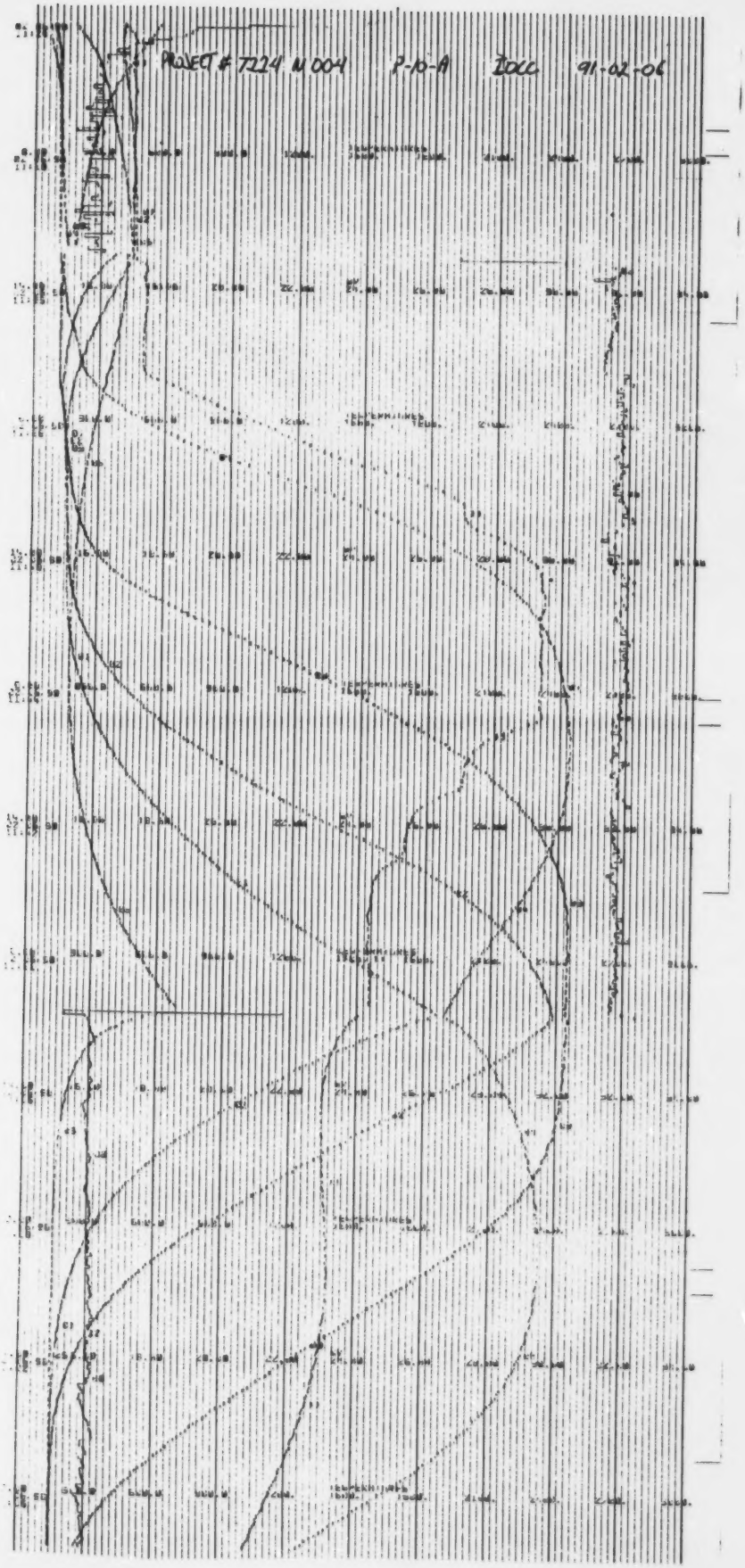
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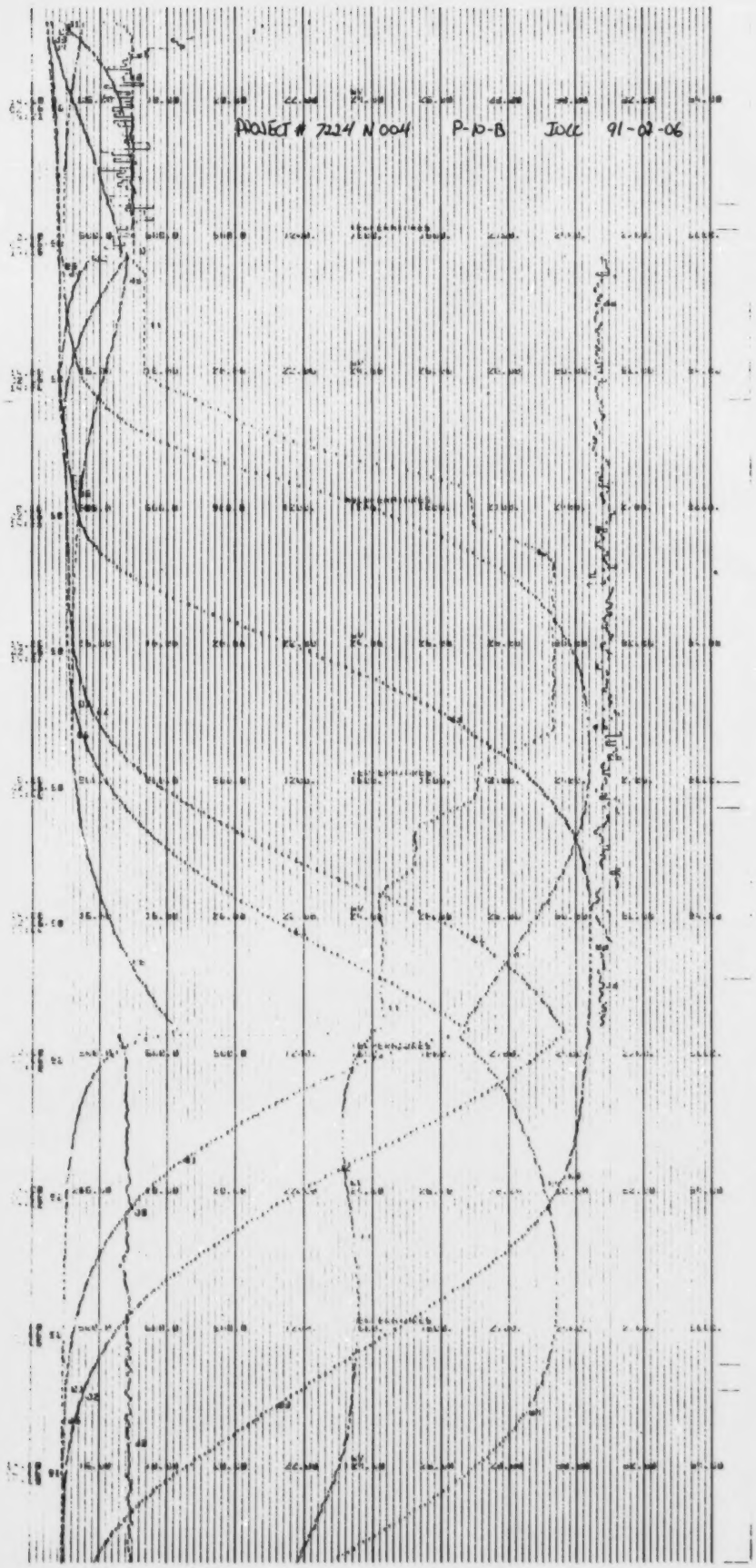
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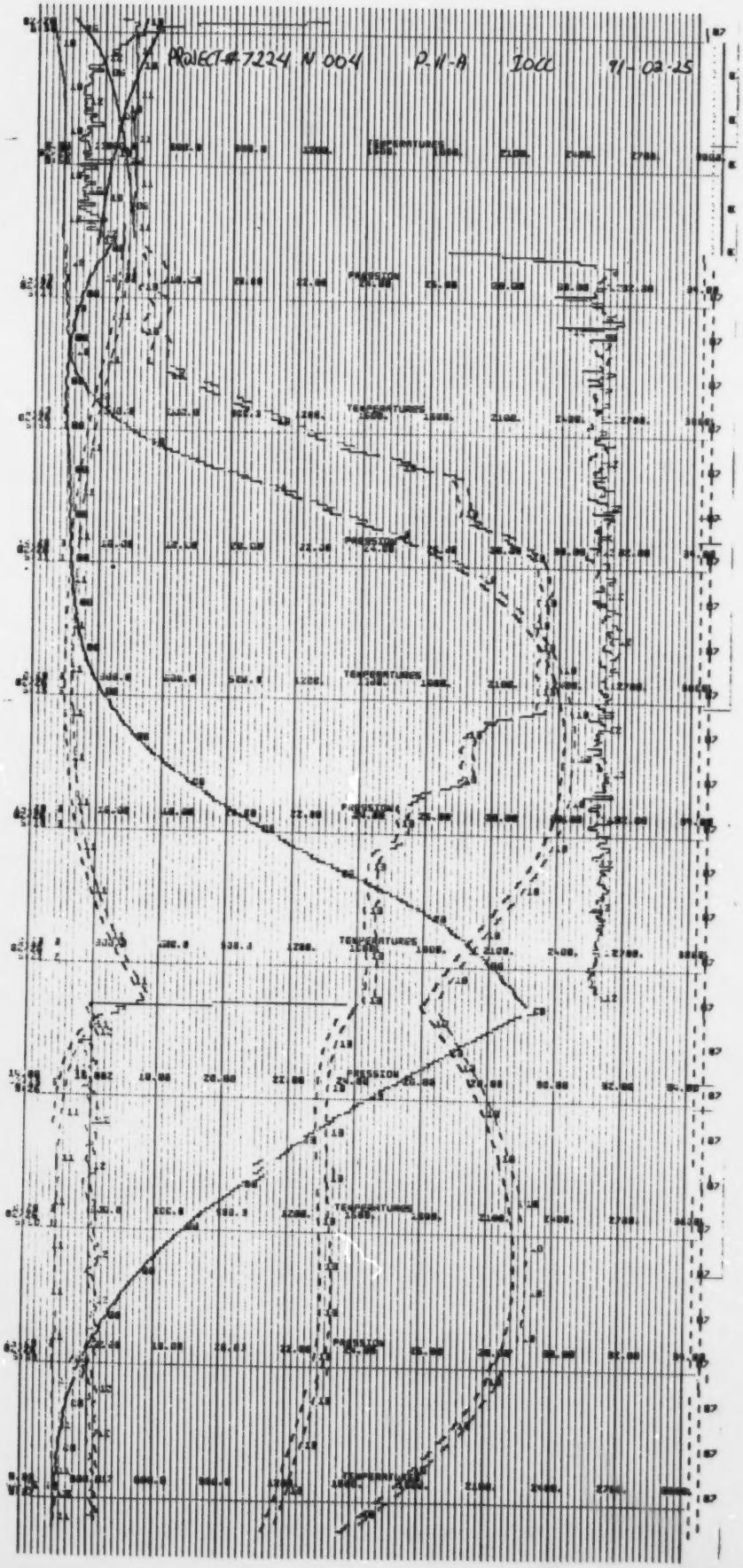
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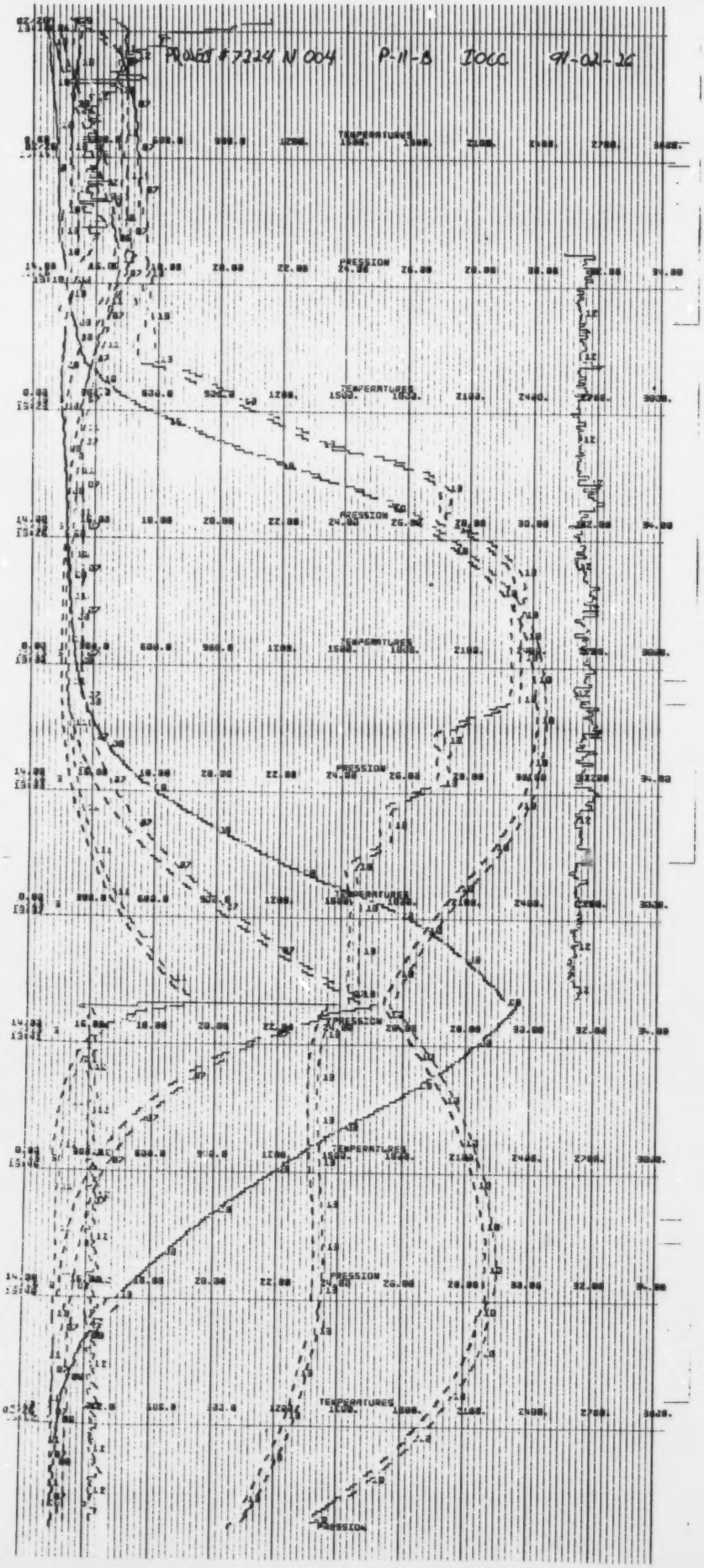
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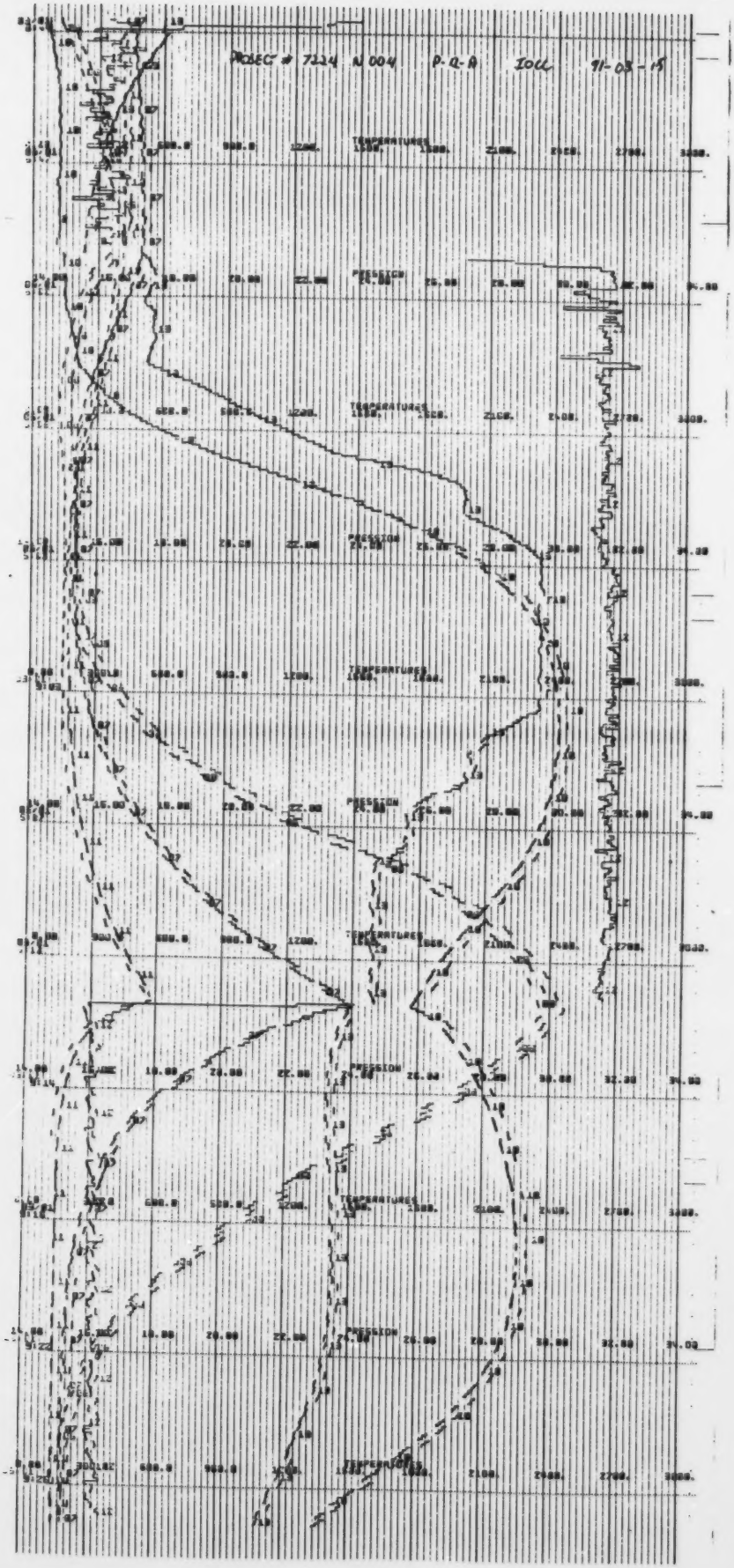
TEMPERATURES
PRESSION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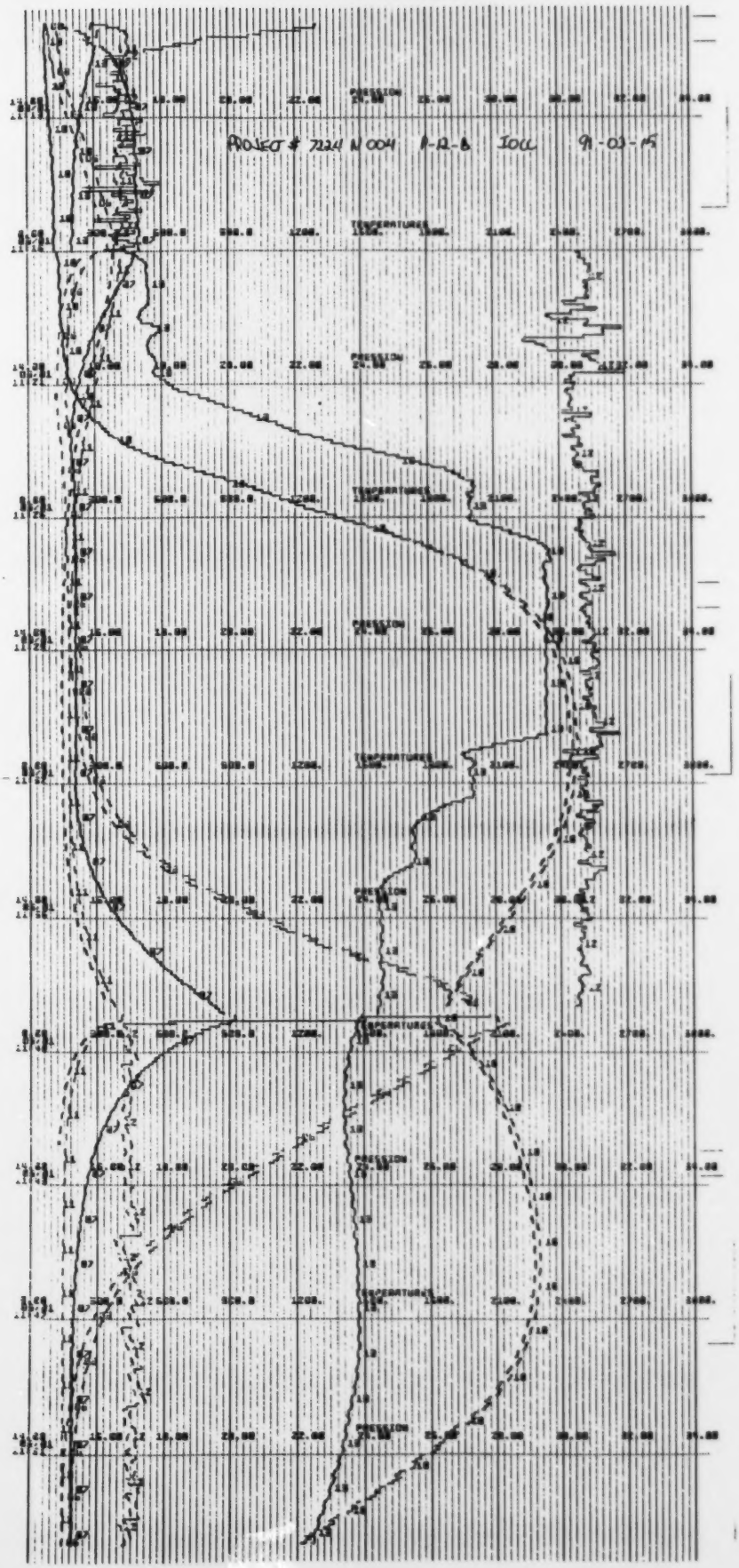
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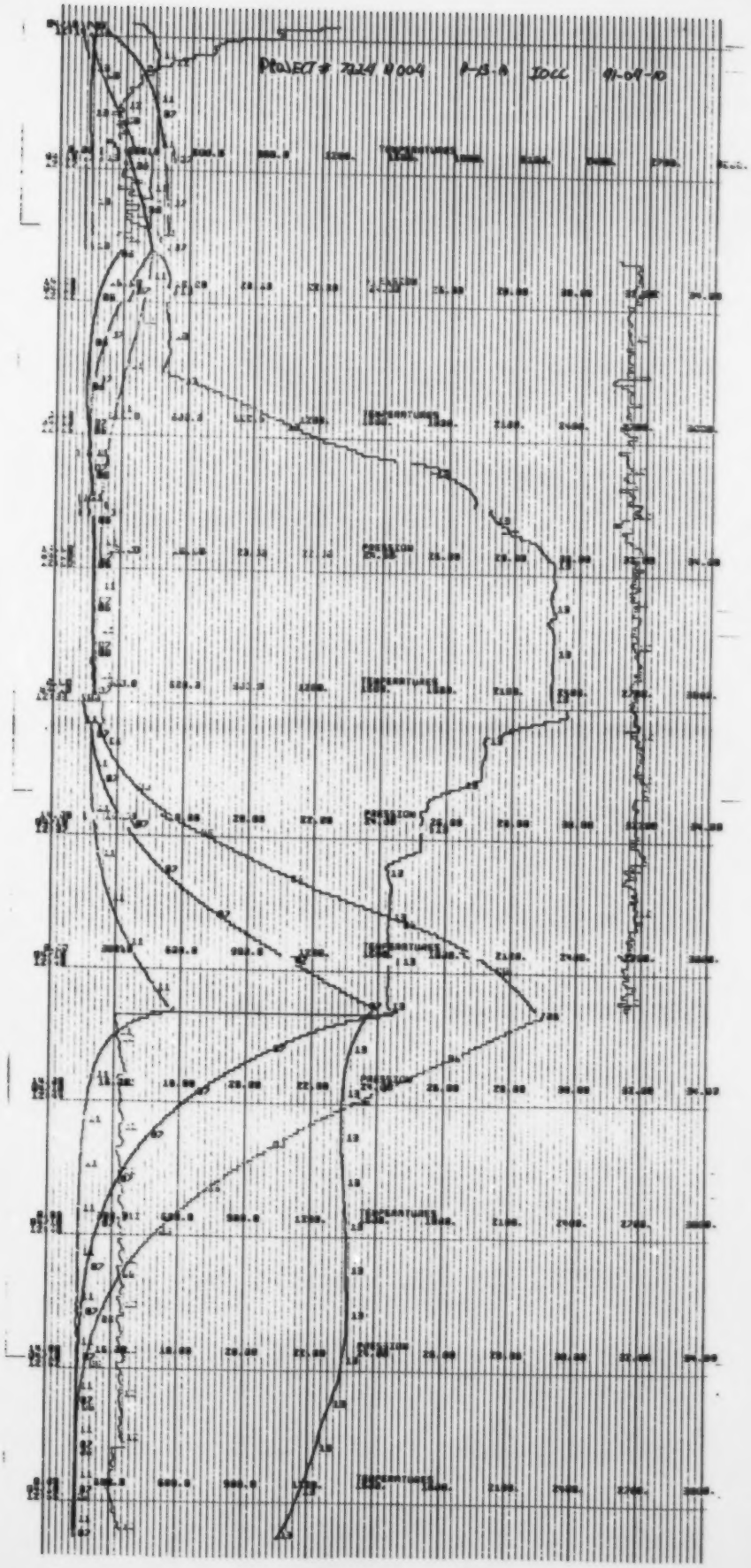
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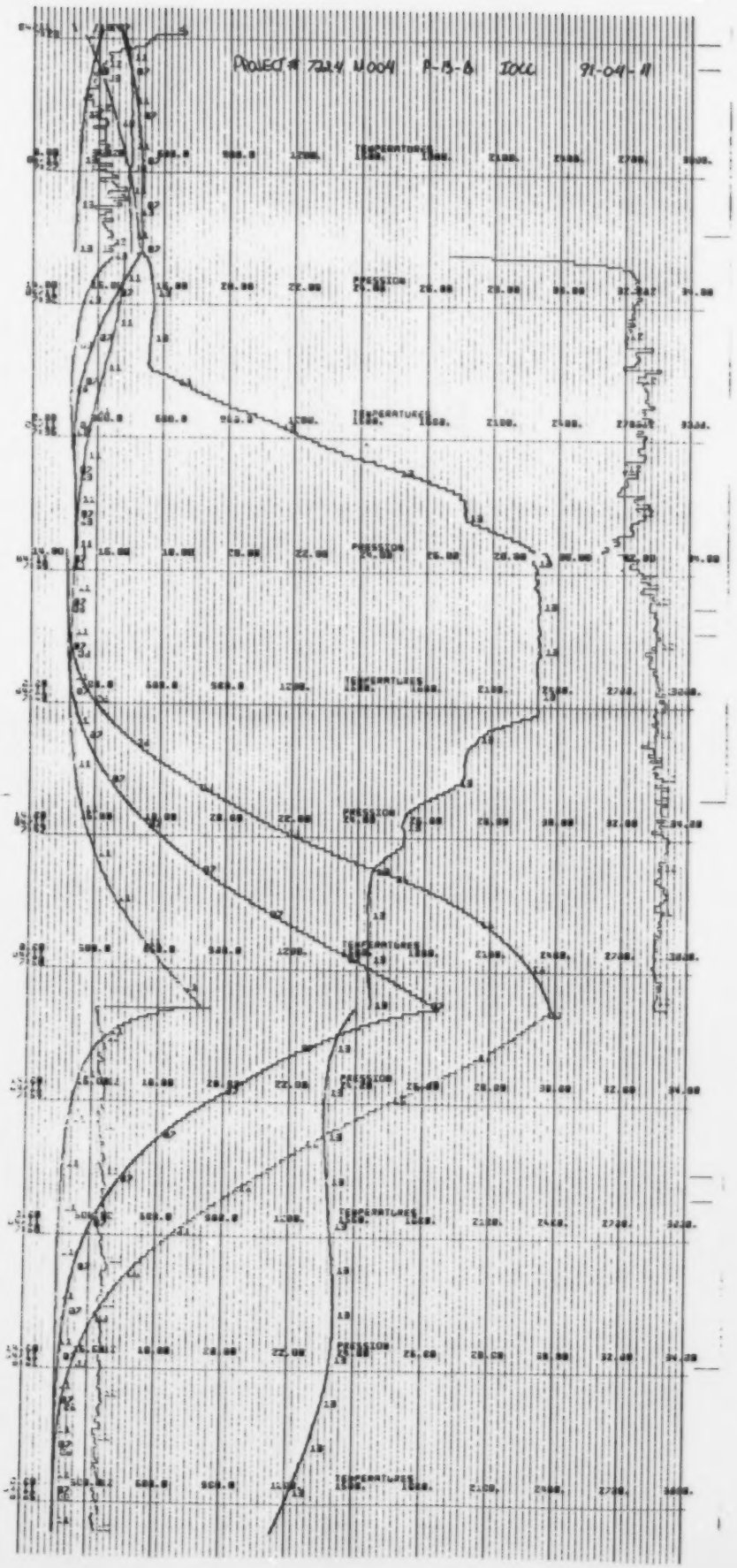
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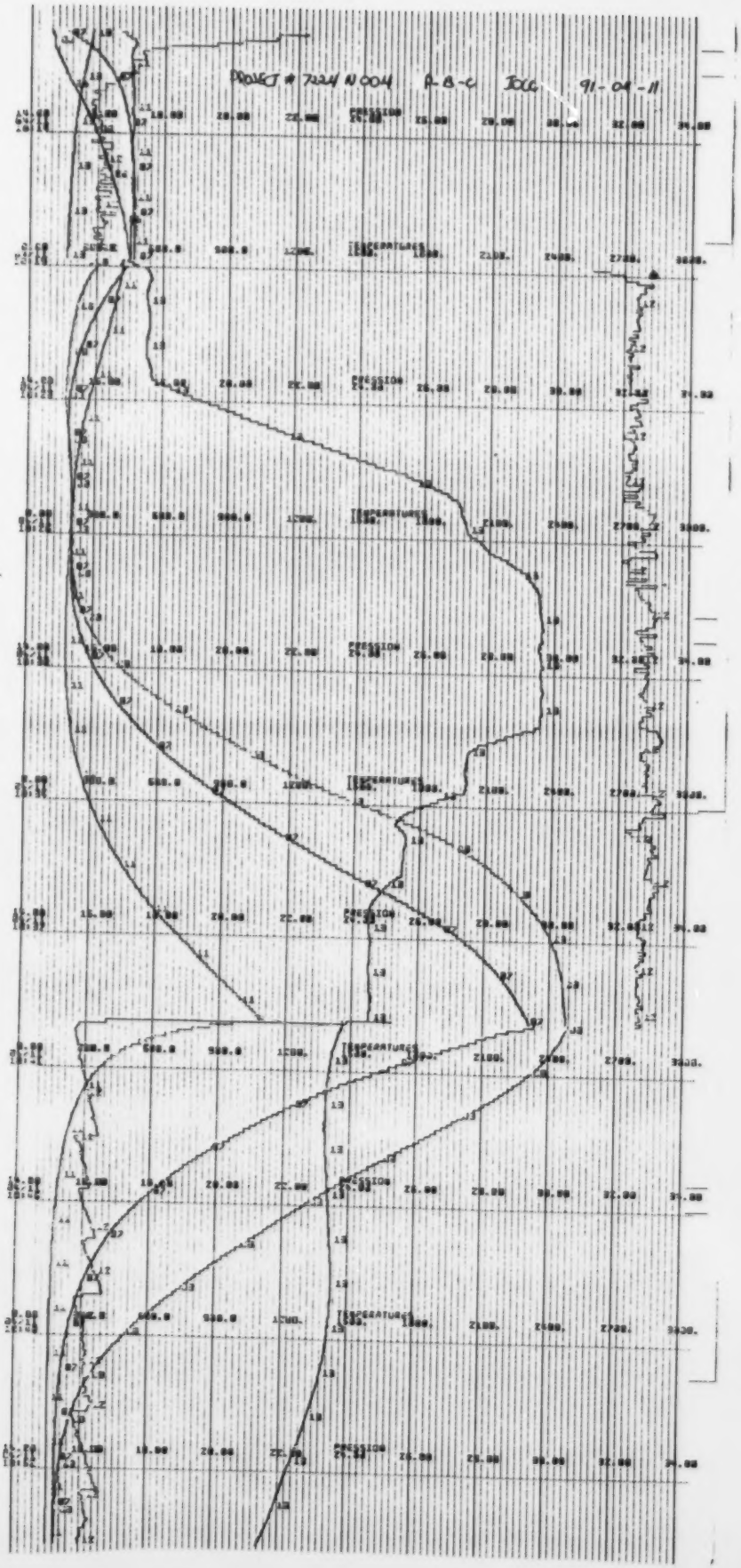
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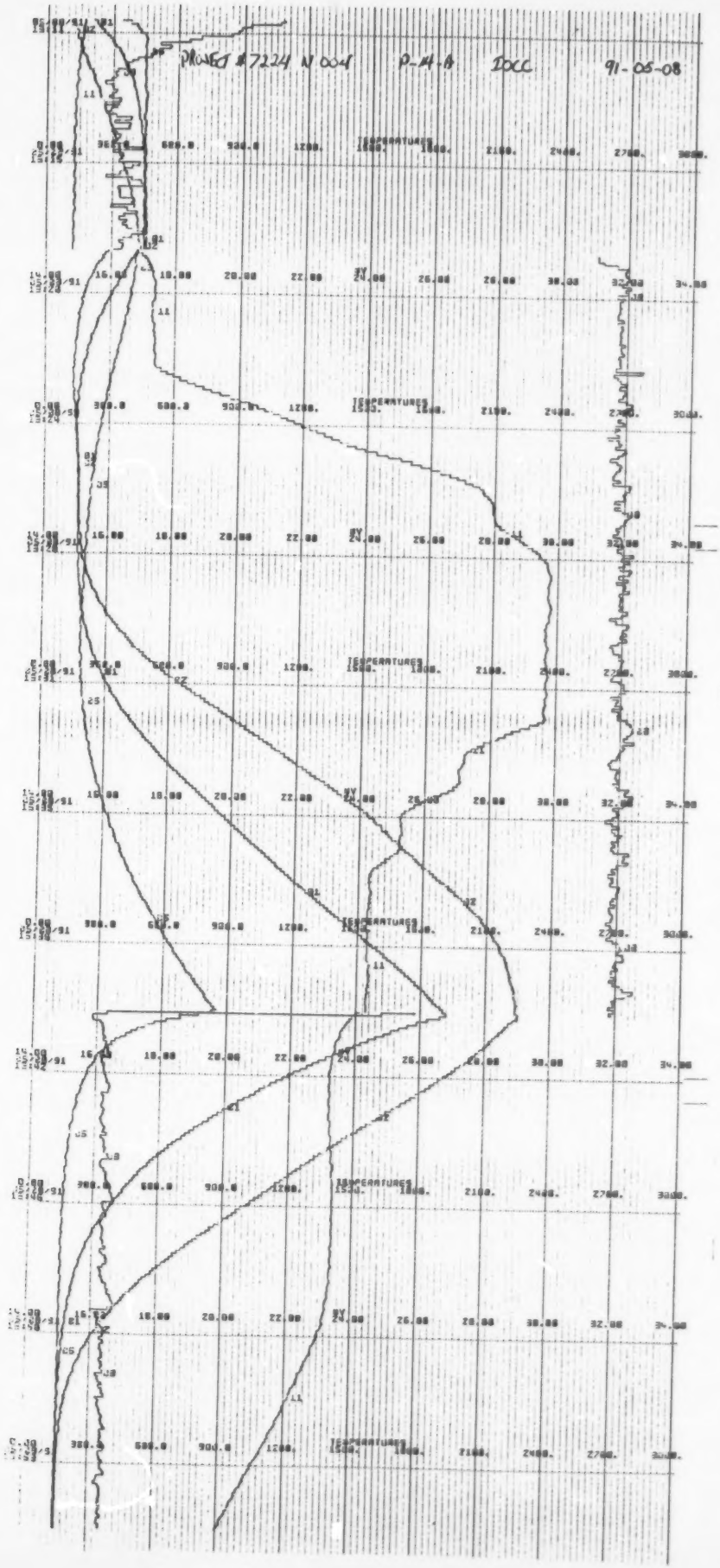
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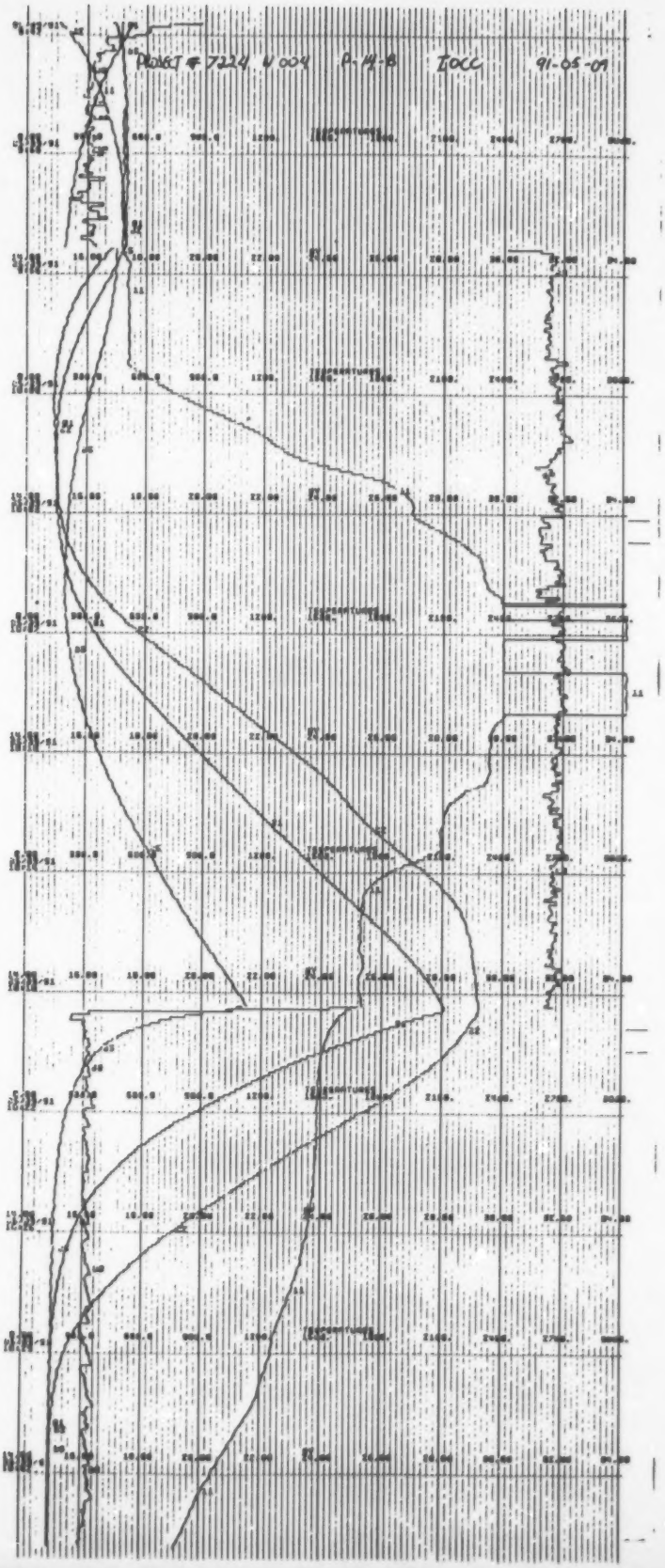
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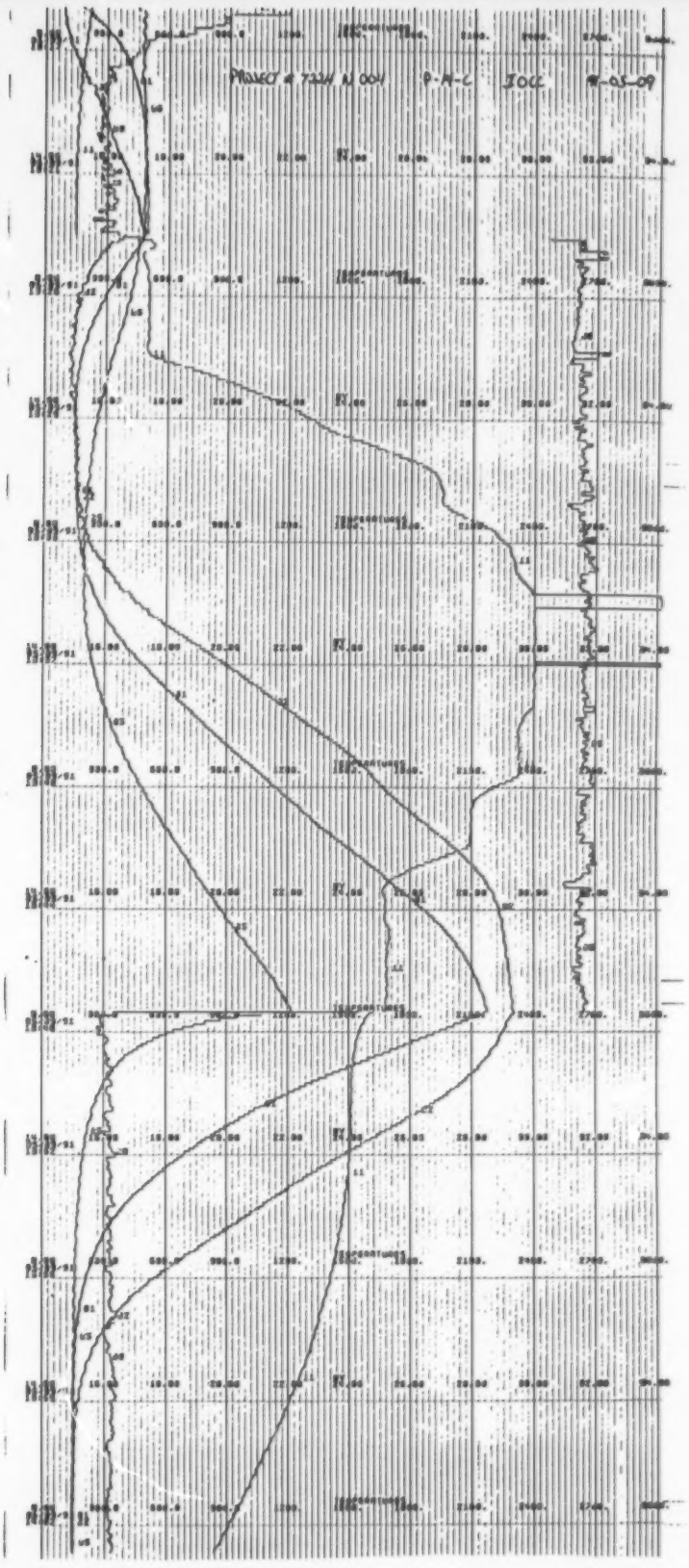
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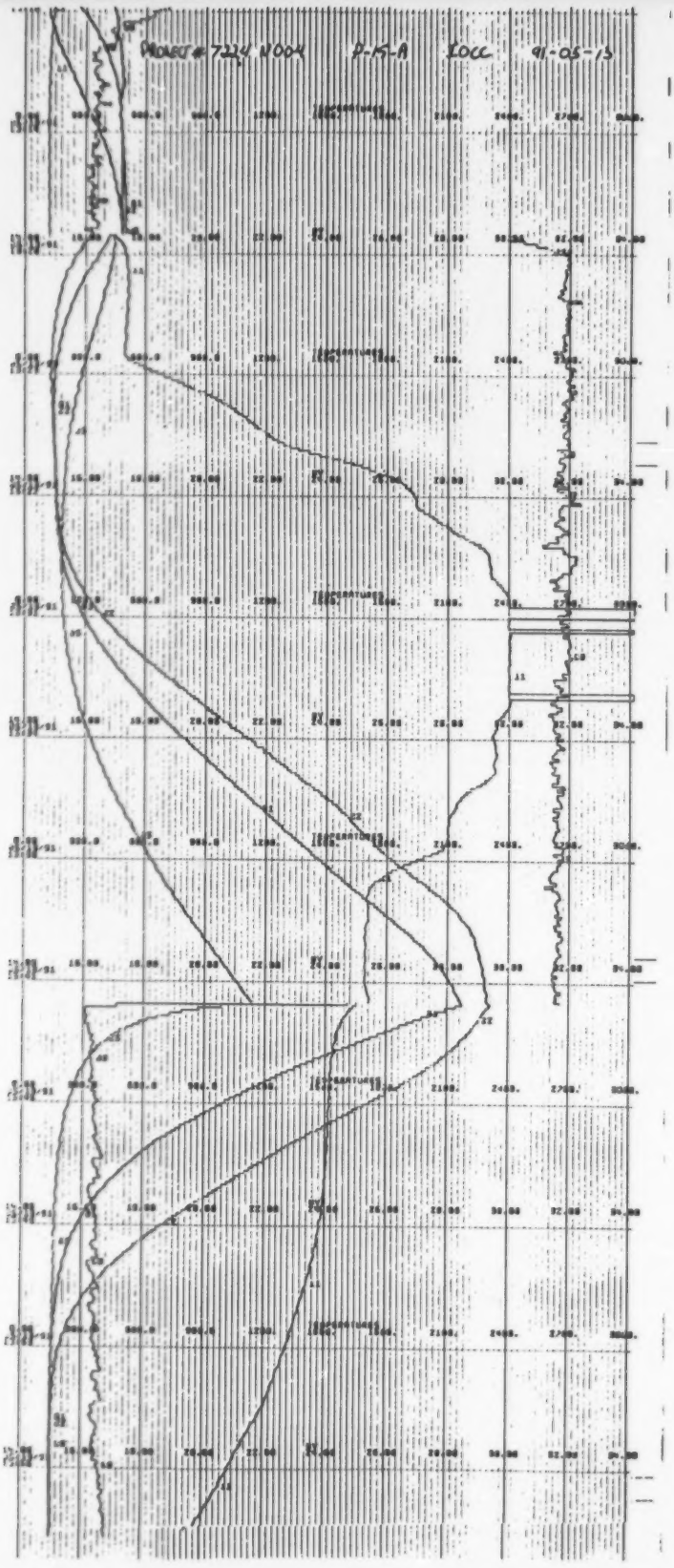
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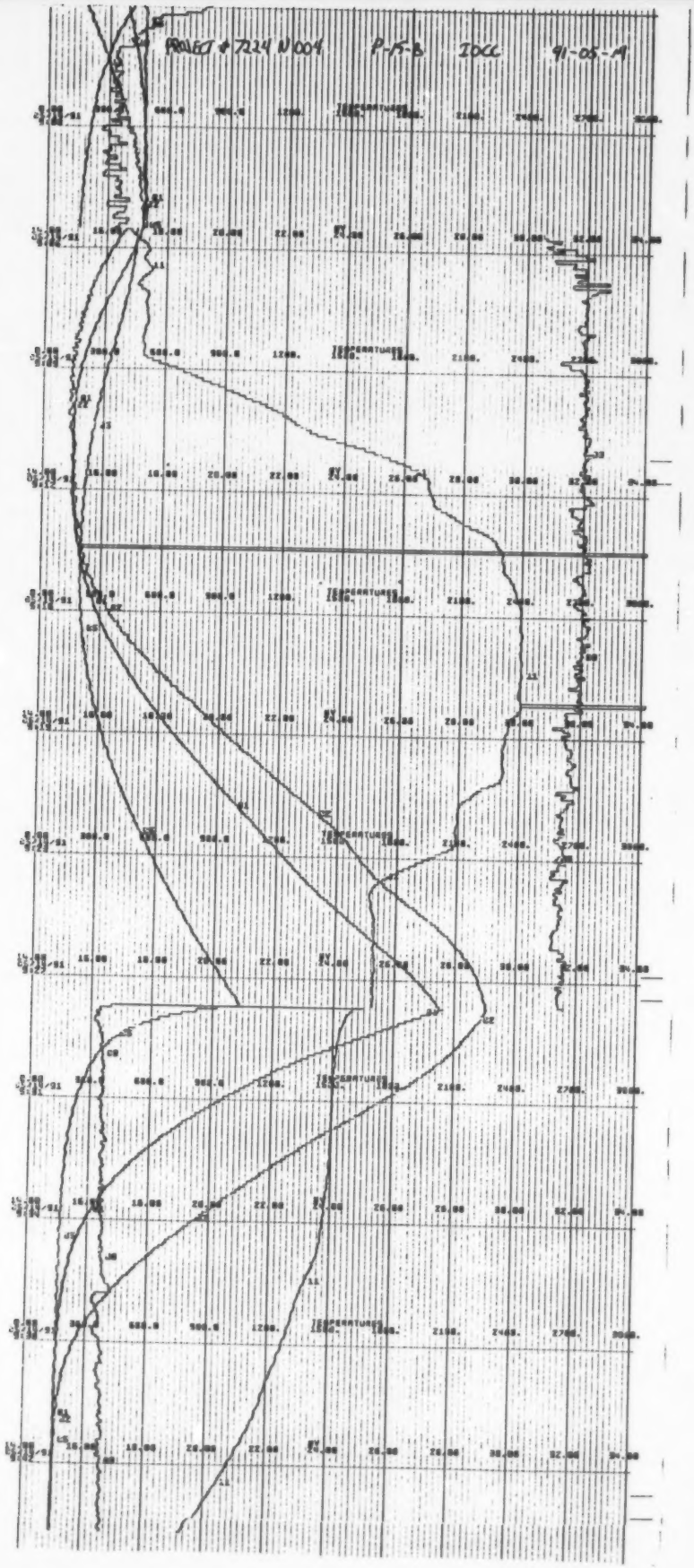
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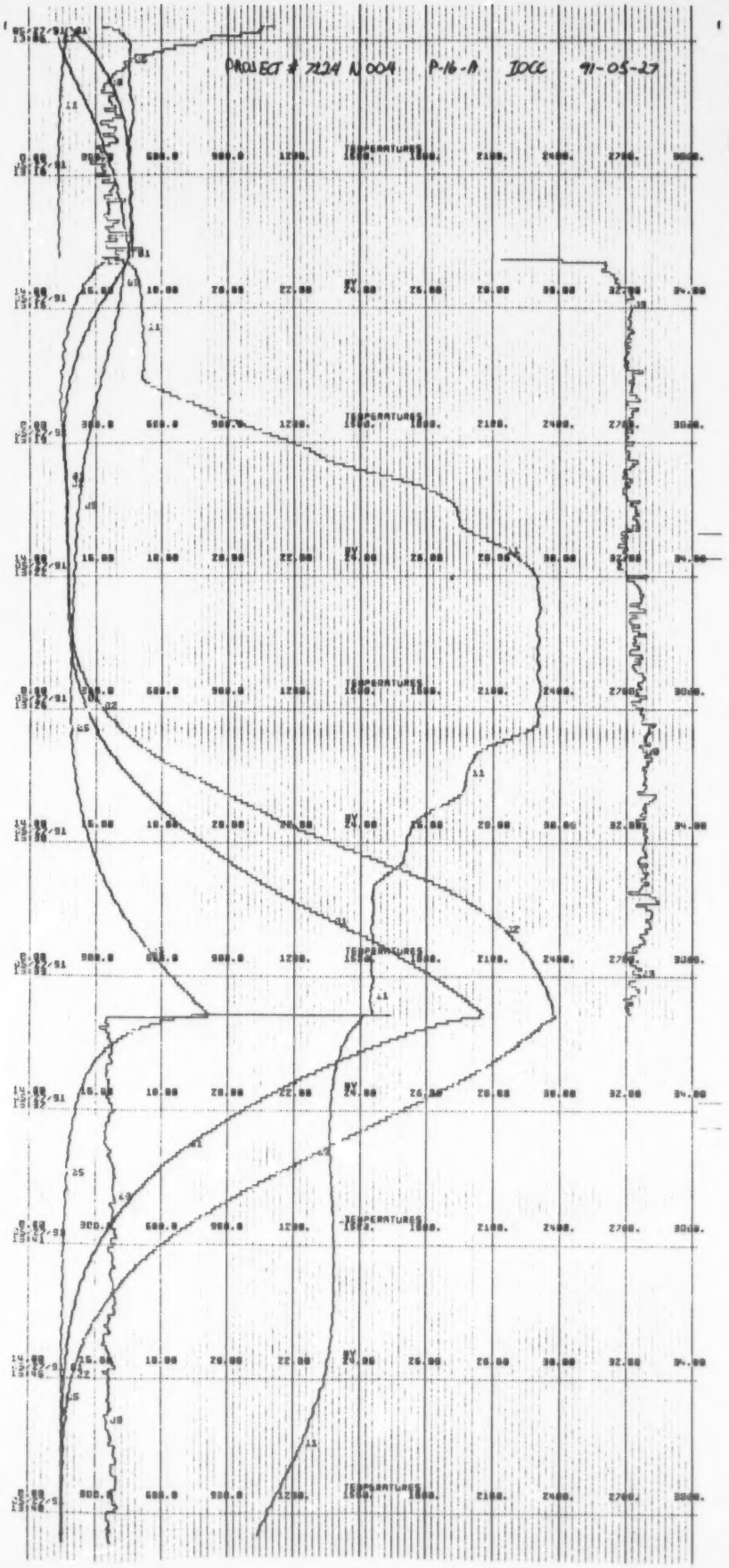
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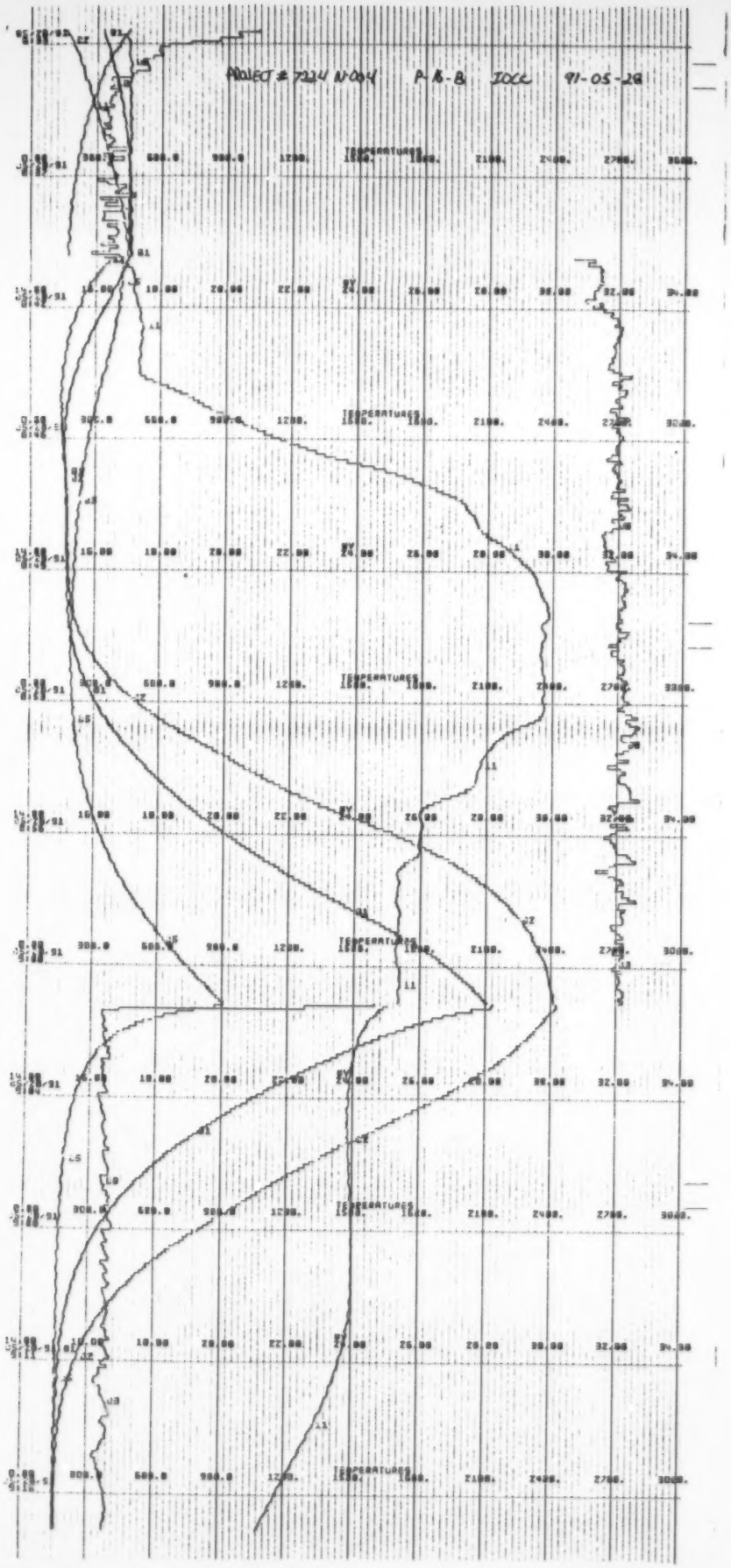
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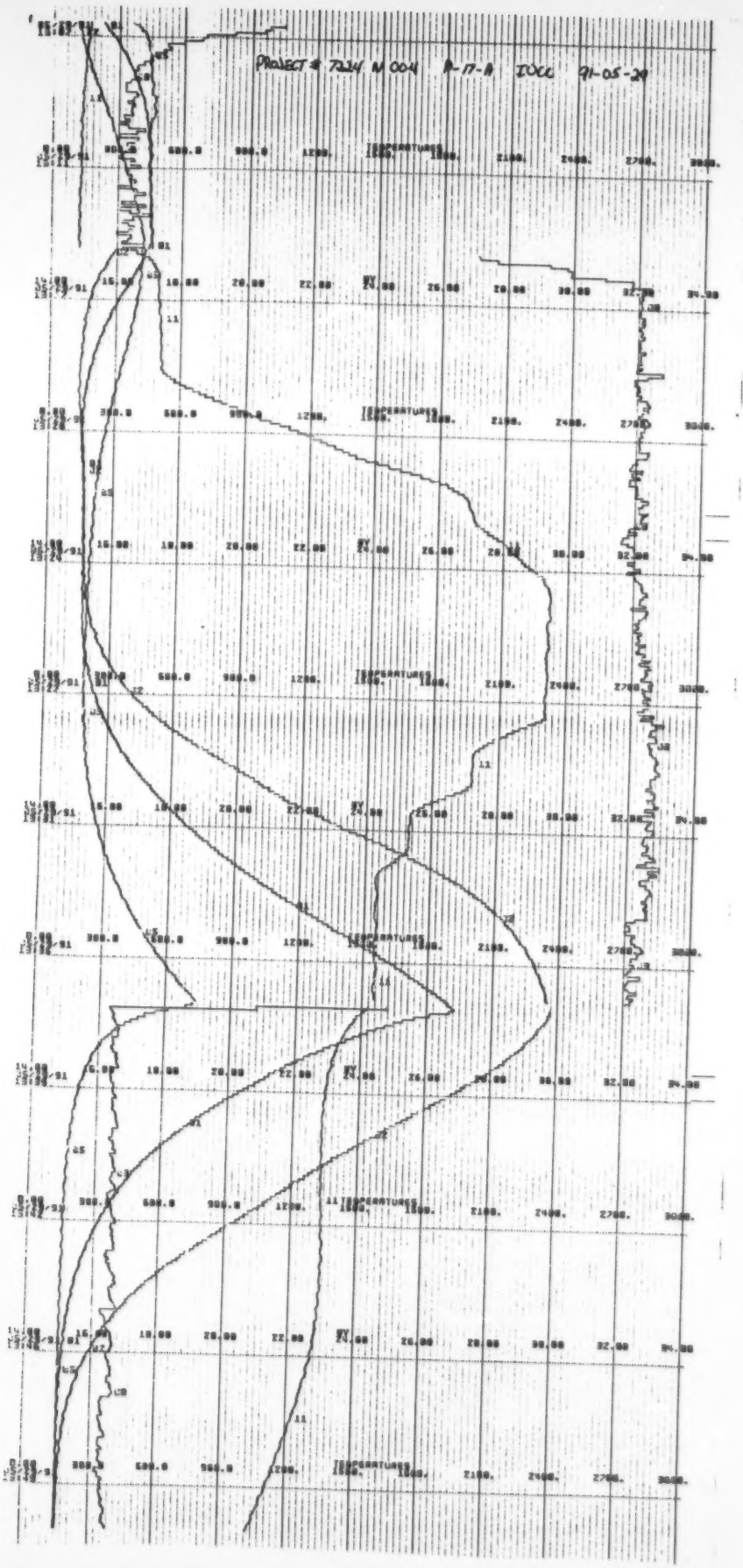
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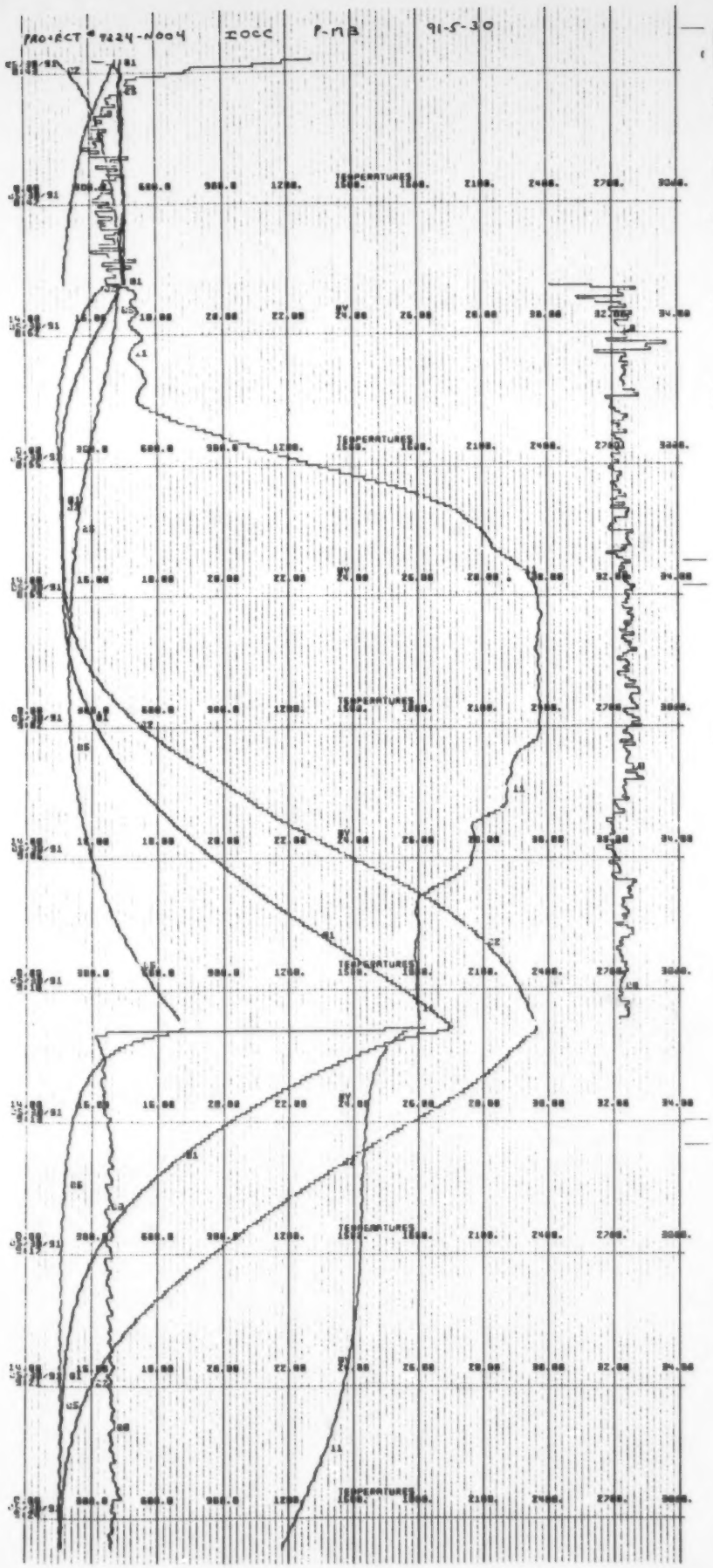
PROJECT 7224-0004
IOCC
P-MB
91-5-30
TEMPERATURES